

**THE GEOLOGY AND MINERAL POTENTIAL OF THE
CORDILLERA REAL, ECUADOR**

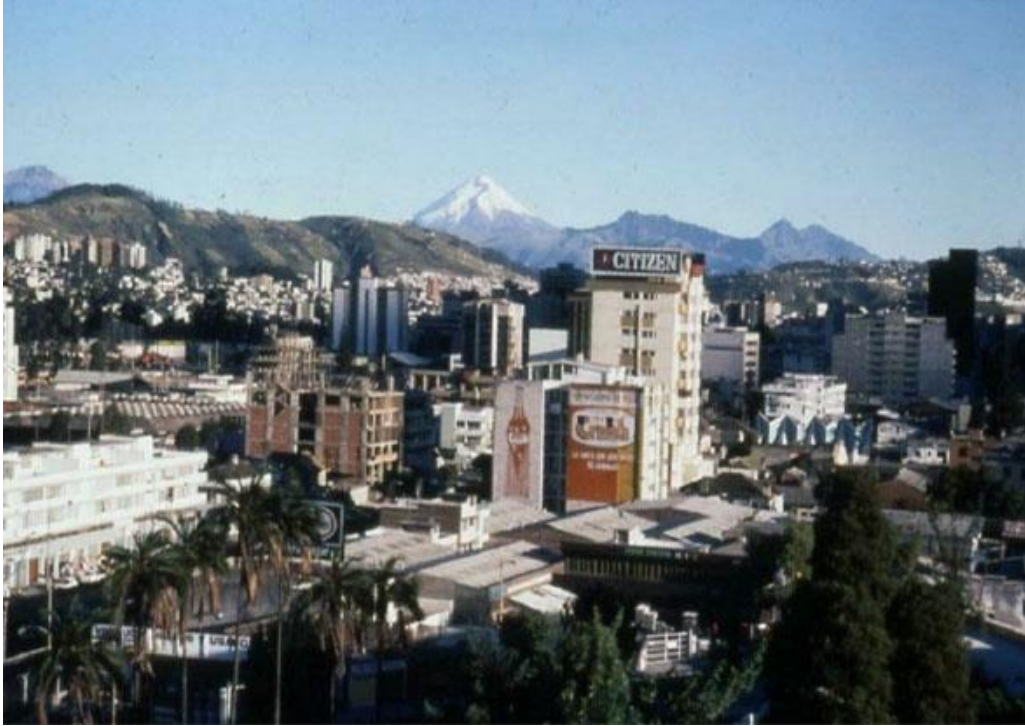
**A summary of the results of the
Cordillera Real Geological Project, 1986-1990,
INEMIN-Misión Británica, Quito**



British Geological Survey

**Keyworth
Nottinghamshire**

PATRI MATRIQUE



View to Cotopaxi Volcano from Martin's office in Quito

Quito, Queen of cities

On the Equator up on high,
The air is thin where condors fly;
Where snow volcanoes fill the sky,
There, queen of cities, do you lie.

Dawn rises on the Milky Way,
On Cotopaxi's slopes doth play;
The sun is warm and here to stay:
An English summer every day.

The exhilaration of the morn
Doth make the spirit feel reborn;
Though years go by, you're never shorn
Of that deep joyfulness of dawn.

At half past six a turquoise hue
Heralds the night-time's gentle dew;
And in the east there looms the view
Of Antisana's ghostly blue.

And quickly as the sun doth set,
The cool of night is on us yet;
Sleeping easy, there is no sweat:
No need for a mosquito net.

And off we go our many ways
And all those Cotopaxi days;
Down the Andes; the river sprays
Into Amazon's gentle lays.

So Quito, queen of cities, you
Inspired my children as they grew;
Please once again come into view,
So we can share your joys anew.

*Martin Litherland
Inca Treasure
Poems from the Andes of Ecuador*



Minor folds and thrusts in semi-pelites, near Ambuqui



Martin Litherland near Cerro Pan de Azúcar

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

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INEMIN-Misión Británica, Quito**

by

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SUMMARY

This report summarises the work undertaken under the Cordillera Real Geological Research Project, a bilateral Anglo-Ecuadorian Technical Cooperation programme. The geology of this largely inaccessible and unexplored eastern Andean cordillera has been divided into five informal Andean-trending lithotectonic divisions. In the west the Guamote division comprises molassic sediments thrust westwards over continental basement. It is bounded eastward by the Peltetec fault, an ophiolitic ?suture, followed by the Alao division of a forearc/island arc greenstone belt of Mid-Jurassic age. Further east are the Baños front fault structure and the Loja division of 'Hercynian' S-type biotite ($\pm$ muscovite and garnet) granites and semipelitic envelope rocks, gneissose in places, with ages possibly as old as the Precambrian. Further east lie the Salado plutonic/island arc belt division and the Zamora continental plutonic/volcanic division, both Jurassic in age. The Zamora rocks are essentially undeformed whilst those of Salado exhibit E-directed nappe complexes containing high level skarn/serpentine klippen. Cretaceous and Cenozoic igneous and sedimentary rocks also occur including a chain of possible Alaskan-type ultramafic pipes.

The mineral potential in the form of metallogenic belts is related to the lithotectonic divisions, with the metals concentrated during collision and in porphyries along collision faults rejuvenated in the Cenozoic. Thus, the two greenstone belts yield polymetallic Ag-Cu-Zn-Pb occurrences, with possible Au and Mo enrichment in the northern skarn-fields, whilst the S-type granite belt underlies Au-scheelite-(Sn) indications. The Nambija Au-skarn relates to roof pendants of a Triassic rift basin within the Zamora batholith. Some of the ultramafic occurrences may be of interest for PGM prospecting.

1. INTRODUCTION

1.1 Statement

This report summarises the four years of work, 1986-1990, undertaken for the Cordillera Real Geological Research Project, Ecuador: a bilateral Technical Co-operation project between the Government of Ecuador (Instituto Ecuatoriano de Minería: Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Overseas Development Administration: Foreign and Commonwealth Office).

1.2 Background

ODA participation in the geological development of Ecuador began in 1969; the first residential mission was established in Quito in 1972. Prior to its closure in 1980, five ODA geoscientists and their Ecuadorian counterparts undertook a programme of systematic geological mapping and mineral investigation over western Ecuador, culminating in the publication of a revised national geological map.

The present project, which began in 1986, represented a renewal of ODA participation in response to the need for a geological and mineral database to foster a viable mining industry. Thus, systematic geological and mineral studies were extended eastwards to cover the Cordillera Real of Ecuador, a poorly explored and inaccessible area known to be an important source of gold.

1.3 Objectives

The subject of the project is to study the metamorphic and plutonic rocks of the Cordillera Real: the objectives are the elucidation of their nature, structure, relationships, genesis and mineralisation in order to discover the patterns of metallogenesis and provide the scientific basis for estimating their mineral potential.

1.4 Residential personnel

The following were seconded to ODA from the British Geological Survey:

Martin Litherland BSc PhD MIMM FGS (Project Leader)

John A. Aspden BSc PhD

The following INEMIN personnel were assigned to the project:

Ing. Ramiro Bermúdez A. (Counterpart Project Leader) (1986-1988, 1989-1990)

Ing. Francisco Viteri S. (1986-1989) (Counterpart Project Leader 1988-1989).

Ing. Miguel Pozo T. (1988-1989)

Verónica Endara C. (Secretary) (1986-1988)

Lcda. Fabiola Alcocer C. (Secretary) (1988-1990)

Manuel Céleri O. (Field Assistant) (1987-1989)

1.5 Area of study: geological constraints

The project has confined its studies to those areas of the Cordillera Real, the Inter-Andean Depression and the Sub-Andean foothills where basement, pre-Cretaceous, metamorphosed and unmetamorphosed rocks are exposed (Fig.2). Limited studies of Cretaceous units over these areas have also been undertaken but the extensive areas covered by Cenozoic volcanics have been largely ignored.

1.6 Topography and drainage

Physiographically, Ecuador can be divided from west to east into the Costa, Sierra, and Oriente (Fig. 1). The Sierra comprises the Andean mountain chain which is at its narrowest in Ecuador (120 km) consisting of two parallel ranges, the Cordillera Occidental and the Cordillera Real, separated by the Inter-Andean Depression in central and northern Ecuador.

Within Ecuador, the Cordillera Real is about 650 km long and 60 km wide. Elevations along its watershed are dominated in the north by a chain of volcanos, the highest being Cotopaxi (5897 m). To the west the Inter-Andean Depression reaches depths of around 2000 m above sea level. Watershed levels fall in the south to around 3000 m. The eastern slope of the Cordillera Real marks a drop to about 1000 m over 30-50 km of ground; streams and rivers are torrential and markedly incised; they join up along the Sub-Andean foothills to form the major rivers of the Oriente, a small sector of the Amazon basin. Only four rivers cross the cordillera: the Chingual, the Pastaza, the Paute and the Zamora.

Over the project area the highest 'metamorphic' peaks are Sara Urcu (4670 m) and Cerro Hermoso (4571 m). Project parties visited both these areas; Cerro Hermoso was climbed.

1.7 Climate and vegetation

There is a tremendous variation in climate and vegetation across the Cordillera Real. The Inter-Andean Depression is temperate with grassland vegetation and rainfall in the region of 700 mm per year (1). The western slope and watershed region is marked by cold, wet moors (páramos) up to the snow-line (4500 m): country usually enshrouded in cloud. The tree-line of the eastern slope montane forest starts at about 3700 m in the north and 3200 m in the south and the climate and vegetation become more tropical as one descends to the eastern lowlands. Rainfall is high over this eastern slope region, varying from 1374 mm per year (Zamora) through 3304 mm (Tena) to 4632 mm (Puyo) (1). Rainfall figures of the high cordillera (1) indicate the months from October to March as 'less wet'; from our own experience a dry day is rare over this period.

1.8 Population

The population of Ecuador is in the region of 10 million. About 40% of these are Indians, the majority of whom are Quechua-speaking descendants of the inhabitants of the Incan Empire and live mainly in the Sierra; a few other small groups exist in the Oriente. Of the remainder about 40% are mestizos and the rest white. To the west of the Cordillera Real the Inter-Andean highway links the rain cities and towns of the Sierra whilst to the east the Sub-Andean highway links the small towns of the foothills (Fig. 2). Over the cordillera itself there are a few small towns and some villages and settlements located along the main access routes (vehicle and animal). Whilst agriculture is the main occupation, a few people make their living by panning gold over the foothill region.

1.9 Access

There are only five vehicles' routes across the cordillera connecting the Inter-Andean and Sub-Andean highways. From north to south these are: Papallacta-Baeza; Baños-Puyo; Cuenca-Limón; Loja-Zamora; and Loja-Zumba; the Guamate-Macas road is still under construction.

South of the Río Paute there are a number of mule trails across the cordillera, but further north extensive segments are without access: e.g. the 120 km of country between the Papallacta and Baños roads contains the Llanganates mountains, traversed recently by the mountaineer Hamish McInnes (1984), within which the legendary treasure of Atahualpa may have been concealed.

1.10 Topographic maps and imagery

Some surveyed maps published by the Instituto Geográfico Militar on scales of 1:50000 or 1:25000 were available in 1986 and others have been issued since; these replace the 'census' maps which are grossly distorted.

Air photo coverage is available on scales varying between 1:40000 and 1:60000; LANDSAT and SAAR imagery can also be obtained. The nature of the surface of the cordillera, either glaciated páramo or heavily forested slopes, coupled with the rapid rate of Andean erosion, prohibits the expression on imagery of lithological units over the metamorphic terrain; the only conspicuous features are neotectonic lineaments.

1.11 Previous geological work

Theodoro Wolf (1892) roughly delineated the metamorphic rocks of the Cordillera Real on the first geological map of Ecuador. Later Sauer (1965) described some of the main lithologies after many years of study along and away from the main access routes. More specific studies have also been undertaken by Feininger (1975, 1982), Trouw (1976) and Herbert (1983), but these were all confined to the road sections.

Reconnaissance mapping of the Cordillera Real began with the studies of Kennerley (1971, 1973) followed by 1:100000 sheet mapping by DGGM (later INEMIN), the bulk of which left the metamorphic rocks undifferentiated.

Some K-Ar geochronology was available (1) (Kennerley, 1980; Herbert and Pichler, 1983; Feininger and Silberman, 1982; Hall and Calle, 1982; Aly, 1980; Baldock, 1982); the Rb-Sr data was statistically invalid.

At the start of the present project, a summary of the geology of the Cordillera Real basement (Baldock, 1982; 1985) indicated a series of schists, gneisses and plutons divided longitudinally into various 'Groups' and correlated laterally with unmetamorphosed Cretaceous formations by some and longitudinally with Palaeozoic or older units of neighbouring countries by others.

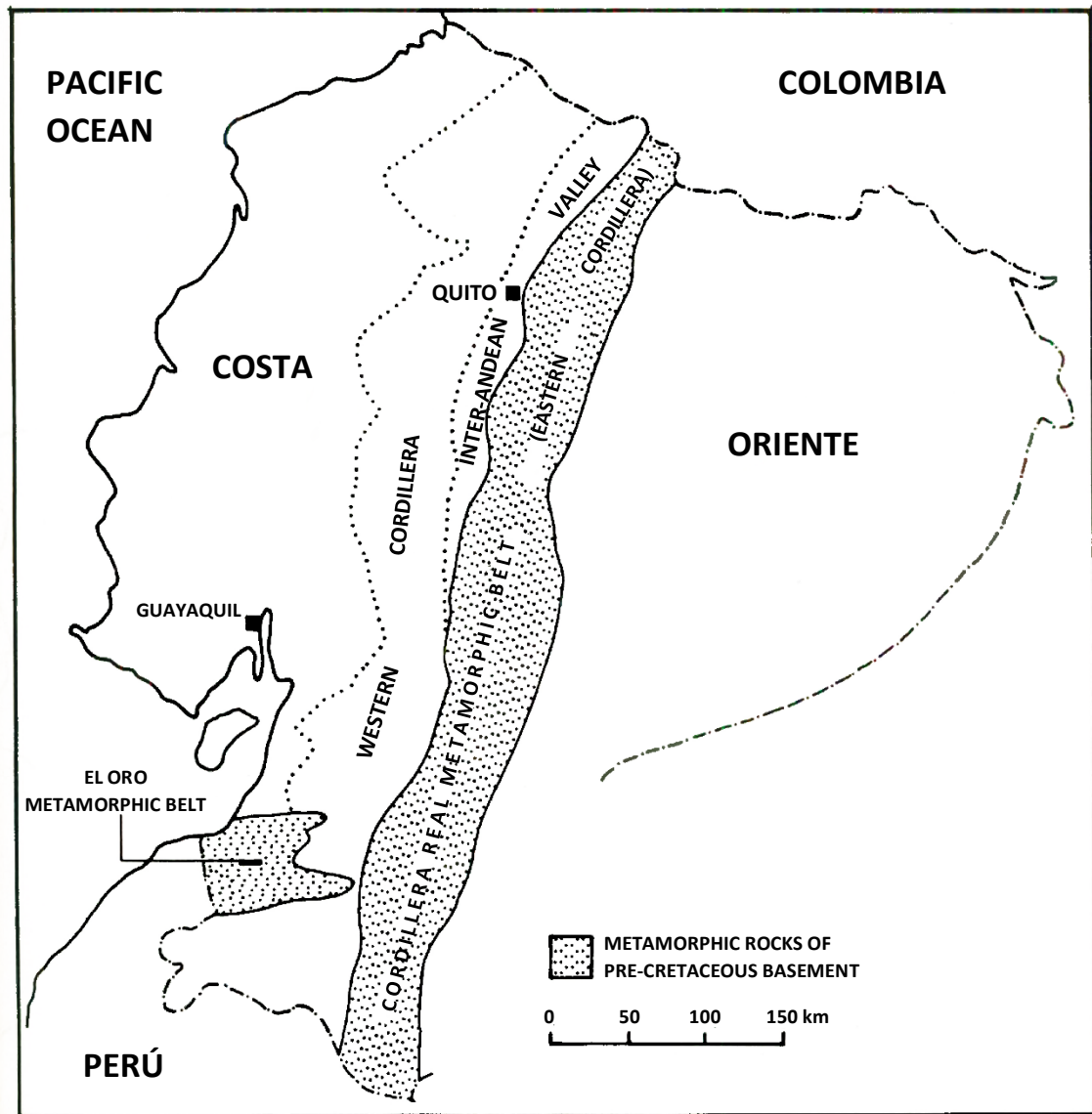


Figure 1. Location map

1.12 Mining and mineral history

At the time of the Spanish conquest, the Incan kingdom of Quito was known for its gold and silver deposits. The Spanish rapidly exploited these during the 16th century: e.g. the hardrock mines of Nambija, Sigsig and Altar, and the placer gold of the Sub-Andean rivers. Indeed, such was the mining fever that of the thirty settlements established by the Spanish, twenty were mining towns along the Sub-Andean zone of the Cordillera Real (Navarro, 1986, Vol. 1). However, mining virtually ceased in the 17th century due to maltreatment of Indians, disease and economic factors.

In more recent years there has been sporadic small-scale working of gold-polymetallic prospects in the project area: Sigsig (Peggy Mine), San Bartolomé and Pilzhum.

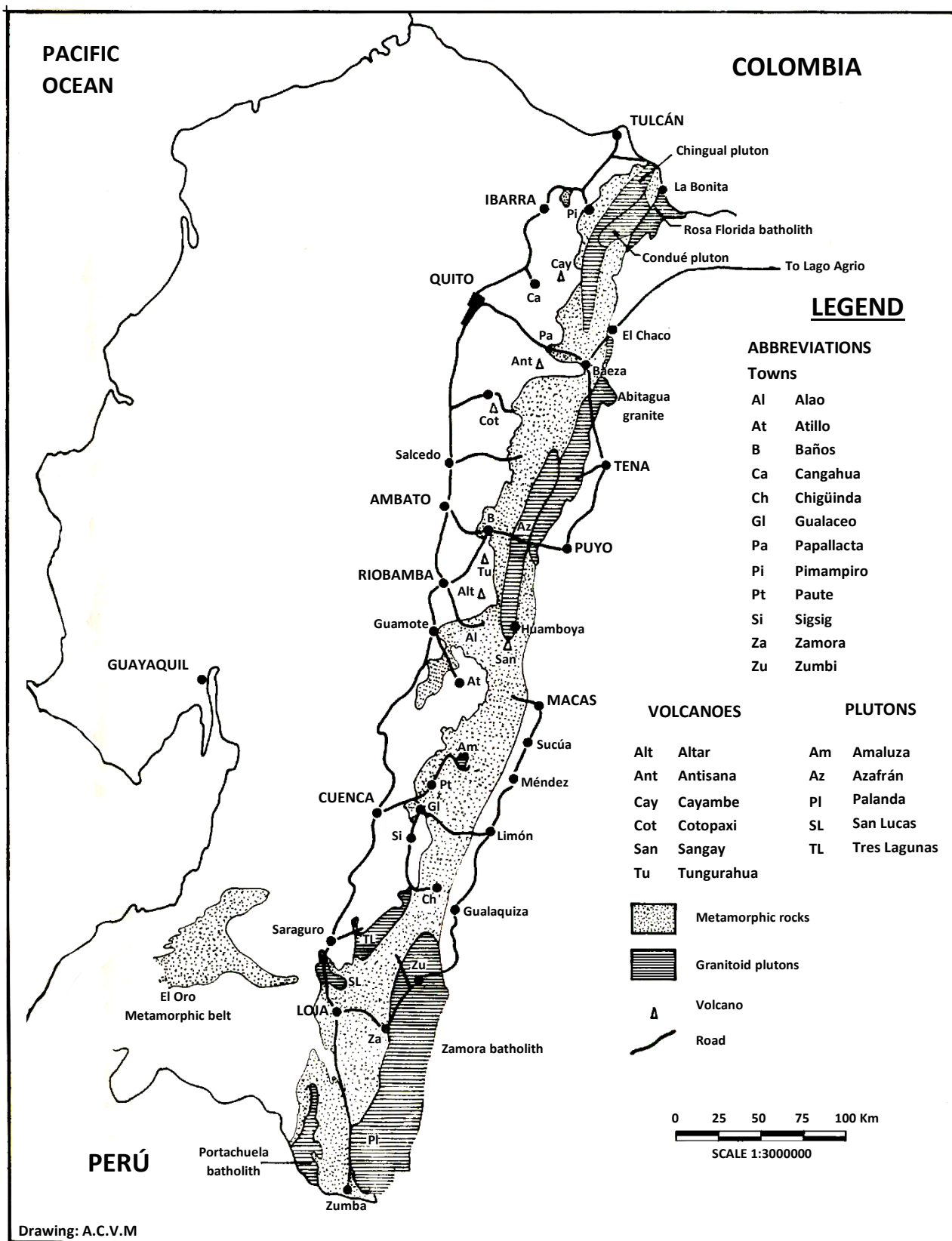


Figure 2. Cordillera Real: population, access and generalized geology

Summary of the results (1986-1990)

The 1980's has witnessed a small renewal of mining interest over the south of the area following the 'rediscovery' of Nambija and the identification of other hardrock deposits nearby. Gold output from Nambija is estimated at between two and four tonnes per year out of a national figure of about ten tonnes. Alluvial and placer gold is also being worked along the Sub-Andean zone and in the mountains along a belt through Sigsig.

Only gold and a few polymetallic prospects were known from the Cordillera Real; there were also occurrences of Sn, Fe, Li, Mo, and Mn minerals (Goossens, 1972; Paladines, 1980). No reports of exploitable non-metallic minerals or gemstones had been recorded.

1.13 Work accomplished 1986-1990

1.13.1 Field studies: reconnaissance geotraverse programme

This programme is indicated on the traverse map (Map 1). The aim was to cross the cordillera along the main access routes with traverse spacings in the region of 20 km. Litherland/Bermúdez/Pozo took the area north of Río Pastaza; Aspden/Viteri the area south of Río Paute: the intervening ground was shared. Over the inaccessible regions of the north, successful traverses took about two weeks (Río Mulatos, Micacocha-Cosanga), but there were also failures due to food supplies running out (Río Condué), or when the physical obstacles became too dangerous (Río Azuela) due to damage caused by the earthquake of March 5th 1987.

A reconnaissance field study was also undertaken of the El Oro metamorphic Province (2).

In order to complete the regional programme in terms of ca. 20 km spacings the following traverses would be required over inaccessible regions:

- (a) Sigsigpamba-Río Dorado-Río Cofanes-Puerto Libre
- (b) Río Chalupas
- (c) Penipe-Río Llushín

Each geotraverse was programmed to obtain the maximum geological data as follows:

- (a) Lithological, mineralogical and structural studies of outcrops.
- (b) Studies of river and stream float and talus blocks: the former provides a lithological collection representing a traverse up to 20 km wide instead of the 20 m river course outcrop.
- (c) Collection of petrological samples.
- (d) Collection of mineralised samples.
- (e) Collection of stream sediment samples.
- (f) Collection of panned heavy mineral samples.

1.13.2 Field studies: follow-up programme

- (a) Follow-up of skarn float in Río Mulatos to discover El Placer skarnfield outcrops (1987: Litherland/Bermúdez) (2).
- (b) Studies of Tampanchi mafic complex (1988: Pozo) (3).
- (c) Studies undertaken by Dr M. C. G. Clarke (visiting short term ODA Economic Geologist) and Viteri on the economic potential of the southern Cordillera Real. (1988) (3).

1.13.3 Geochronological programme

- (a) 10 reconnaissance samples were analysed by the K-Ar method by Dr C. C. Rundle (1).
- (b) In 1987 the first major geochronological programme was undertaken over the Cordillera Real. Dr C. C. Rundle (visiting short term ODA geochronologist)/Aspden/Viteri/Bermúdez collected 130 samples which were processed at the INEMIN laboratories, Chillogallo by Srs. Casanova and Rodríguez. Rundle analysed 74 samples by the K-Ar method and 98 by the Rb-Sr method in UK (2, 3).
- (c) The second programme was undertaken in 1989 over the Cordillera Real and El Oro metamorphic areas. Dr S. M. Harrison (visiting short term ODA geochronologist)/Aspden/Viteri collected 99 samples: 54 for Rb-Sr studies; 57 for K-Ar; 20 for Sm-Id and one for U-Pb (4).

1.13.4 Heavy mineral studies

- (a) The bulk of the 311 samples collected during the field programme have been analysed by Bermúdez (4), following his training scholarship in heavy mineral identification at BGS. Sample preparation was by Sr. G. Erazo (INEMIN).
- (b) Ten samples collected from the Río Mulatos were analysed by R. Ixer (Aston University) for BP Minerals (2).
- (c) 61 samples collected over the south of the cordillera by Clarke/Viteri were analysed by B. Beddoe-Stephens (BGS) for ODA (3).
- (d) 106 project samples have been scanned by XRF at Quito Polytechnic by M. Arauz de Toapanta.

1.13.5 Stream sediment geochemistry

320 stream sediment samples, sieved in the field to less than 80 mesh (clay and silt) size, were analysed for trace elements at the INEMIN laboratories, Chillogallo, by R. Buitron, F. Guevara, P. Jara, M. López, S. Naveda, S. Salvador and C. Toscano (1, 2, 3, 4); some were analysed for more elements than others.

It should be noted that these and the heavy mineral samples were collected where convenient rather than on any statistical basis.

1.13.6 Rock geochemistry

- (a) 112 rocks, mostly mineralised samples, were analysed for specific trace elements at the INEMIN laboratories (1, 2, 3, 4).
- (b) 113 rocks were analysed for a full range of trace and major elements at ACME laboratory, Vancouver, for Río Tinto Zinc (formerly BP Minerals) (2, 3, 4). These included skarn and mafic/ultramafic suites.
- (c) 155 mineralised samples collected by Clarke/Viteri were assayed for precious and base metals by Caleb Brett (UK) for ODA (3).
- (d) 19 granitoid rocks were analysed for major and trace elements by Caleb Brett (UK) for ODA (3).
- (e) 14 samples were analysed for trace elements by Caleb Brett (UK) for Greenwich Resources (4).
- (f) 57 samples from the geochronological collection were analysed for major and trace elements by Keele University for ODA (4).

1.13.7 Petrographic studies

- (a) Over 1000 microscopic thin sections have been cut for the project by Sr. J. Paucar of the INEMIN laboratory and studies by the project team have been summarised (1, 2, 3, 4).
- (b) Dr N. J. Fortey (visiting short term ODA petrologist) undertook petrographic studies of various suites (ultramafic/mafic, skarns, granitoids) from the collection in Quito (4).
- (c) A petrographic examination of eight samples of Río Mulatos skarns was made by A. Thompson for BP Minerals (1).
- (d) A petrographic examination of 31 samples of Río Mulatos/El Placer skarns was undertaken by P. J. Williams (London University) for BP Minerals (2).
- (e) A petrographic study of four samples from the Tres Lagunas granite suite was made by M. P. Atherton (Liverpool University) for BP Petroleum (2).
- (f) Petrographic studies of 25 rocks mainly from the Tres Lagunas suite was undertaken by J. Dangerfield (BGS) for ODA (3).

1.13.8 Mineral studies

Microprobe studies on 19 polished thin sections from samples collected by Clarke/Viteri, were undertaken by B. Beddoe-Stephens (BGS) for ODA (3).

1.13.9 Fluid inclusion studies

Studies were undertaken on 12 samples from Nambija and Portovelo by T. J. Shepherd (BGS) for ODA (2).

1.13.10 Gold analysis

- (a) A pilot examination of 19 samples of alluvial and in situ gold and platinum was made by B. Beddoe-Stephens (BGS) of ODA (1).
- (b) Gold analysis was carried out on 19 samples from the southern mining areas, collected by Clarke/Viteri, by B. Beddoe-Stephens (BGS) for ODA (3).

1.13.11 Palaeontological studies

- (a) There are three reports on Sinemurian and Cretaceous ammonites by H. Ivimey-Cook (BGS) for ODA (3).
- (b) There are six palynological reports by S. G. Molyneux, J. B. Riding and J. E. Thomas (all BGS) for ODA (3, 4).
- (c) There is a report on fossil fish by C. Patterson (Nat. Hist Mus.) for ODA (4).
- (d) There is a report on conodonts by Nottingham University for ODA (3).

1.13.12 Project topographic base map

The project team has compiled, and continuously upgraded, a 1:250000 topographic base map of the project area from existing IGM surveyed sheets and LANDSAT images.

1.13.13 Field reports and maps

32 comprehensive field reports by the project team accompanied by geological and sample location maps at scales of 1:50000 or 1:10000 were presented to INEMIN (in Spanish).

1.13.14 Project Annual Reports

- (a) Four Project Annual Reports have been compiled. Each comprises the annual database in the form of Appendices (including the field reports) along with a summary in English or Spanish. Field-maps are presented in a separate binder along with 1:250000 scale maps of yearly work areas. The present report is essentially a summary of the four Annual Reports.
- (b) The number references in this report refer to the individual Annual Reports.

1.13.15 Publications

Project team members have published in local journals and these are referred to in the text.

1.14 Acknowledgements

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2. GEOLOGY

2.1 Lithotectonic divisions of the pre-Cretaceous metamorphic complex

At the beginning of the project (1) it was decided to abandon the previous formalised lithostratigraphic nomenclature for the Cordillera Real, e.g. the “Groups” of Llanganates, Zamora, Cofanes, Margajitas, Ambuquí and Paute (Baldock, 1982), for the following reasons:

- (a) There was little or no scientific base, e.g. Hedberg (1976), for their erection by previous workers: i.e. no top, base, thickness, age, type section, component formations, stratigraphic relations etc.
- (b) Field reconnaissance showed these “Groups” to be ‘bucket’ terms for a variety of metamorphic and meta-igneous lithotypes separated, in places, by major faults.

In place of the disbanded nomenclature the metamorphic complex of the cordillera was divided informally into three tectonic belts each with its own litho(tectonic) divisions (1), and this system has been amended each year to suit new data. At present (Table 1) the system takes the form of five lithotectonic divisions each with a degree of geological coherence as illustrated by their respective subdivisions. The aim has always been to erect a framework, based on lithological affinities and fundamental faults, which will accommodate objective description without imposing rigid formality. This framework can then be interpreted in terms of fashionable or unfashionable theory; for example, one or more of the present lithotectonic divisions may be a terrane sensu Coney et al. (1980).

2.2 The Guamote division

2.2.1 Lithologies of the Guamote division

Rocks of this unit crop out in basement inliers on the western slope of the cordillera between Riobamba and Cuenca, and in the Inter-Andean Valley near Ambuquí in the extreme north. There are excellent exposures along the Pan American highway just south of Guamote and near Ambuquí.

Over the Riobamba - Cuenca localities, the division is bounded by the Ingapirca fault in the west and the Peltetec fault in the east; forming a belt up to 15 km wide. Outcrops extend from the Punín inlier in the north to the Río San Pedro east of Cañar in the south, a distance of ca. 100 km. The Punín subdivision includes the “Ingapirca Formation” interpreted by Bristow et al. (1975) as part of the Yunguilla (Maastrichtian) cover sequence.

The division comprises orthoquartzites intercalated with low-grade phyllites or slates; the subdivisions (Table 1) are based on the dominant lithology. Thus, the Guasuntos and Cebadas (pelitic) subdivisions comprise black or grey slates with subordinate black or grey, fine- to medium-grained quartzites, whilst in the Punín subdivision quartzites predominate over the pelitic beds.

Table 1. Informal lithotectonic divisions and subdivisions of the pre-Cretaceous rocks of the Cordillera Real

DIVISION (interpretation)	SUBDIVISION	PRINCIPAL LITHOLOGIES
GUAMOTE (continental sediments/clastic wedge)	Ambuquí	Quartzites and black slates
	Cebadas	Black phyllites and black quartzites
	Guasuntos	Black phyllites and black quartzites
	Punín	Red, black and pale quartzites and phyllites
PELTETEC FAULT		
ALAO (ocean floor, fore-arc, volcanic arc and back-arc)	Peltetec	Dismembered ophiolitic assemblage
	Pacheco	Basaltic greenstones
	Maguazo	Turbidites, cherts, carbonates, andesites, ?olistromes.
	Alao-Paute	Andesitic greenstones, greenschists, agglomerates, minor phyllites.
	El Pan	Volcano/metasedimentary units: green- schists and phyllites.
BAÑOS FRONT		
LOJA (continentally- derived unit: phyllite to paragneiss with 'S- type' granites)	Tres Lagunas	Biotite granite and orthogneiss (S-type character)
	Agoyán	Pelitic schists and paragneiss, common garnet
	Chigüinda	Semipelite (quartzite, black phyllites, schists), minor greenstones
	Sabanilla	Medium-to high-grade orthogneiss and paragneiss
	Monte Olivo	Basaltic amphibolites
SALADO (plutonic unit with volcano-sedimentary sequence)	Santa Bárbara	Biotite ± hornblende ?paragneiss
	Azafrán	Sheared calc-alkaline batholiths
	Upano	Greenstones, metatuffs, metagreywackes and metasediments; minor marbles
	Cerro Hermoso	Marbles and metasediments
APPROXIMATE CRATONIC LIMIT		
ZAMORA (continental plutonic/volcanic arc and olde metamorphics)	Abitagua	Calc-alkaline batholiths (undeformed)
	Misahuallí	Andesites, dacites, basalts, agglomerates (undeformed)
	Isimanchi	Marbles, immature low-grade metasediments and metavolcano-sedimentary units (pre-Abitagua)

The Punín (quartzitic) subdivision exhibits lithological changes from north to south. In the Punín inlier and Guamote sector the quartzites are pale- to medium-grey, pink or red in colour and vary from medium-grained feldspathic types through coarse-grained types to conglomerates with clasts up to 1 cm across. These are intercalated with black, grey, purple, green, or pale slates, which, in the quarry 200 m E of Punín are essentially unmetamorphosed. Other features are the presence of fine ferruginous sandstones, and clay concretions, ferruginous in places, up to 20 cm across, in the quartzites. The coarse quartzites show subrounded to angular clasts dominated by milky quartz with subordinate clasts of smoky quartz, mudstone pellets and pyrite-rich, fine-grained, recrystallised acid volcanics, in a matrix of more-rounded fine quartz.

Further south, around Palmira, the conglomerates remain pale grey but the quartzites are grey or black due to the presence of smoky quartz. Clasts of blue quartz were also noted. The pelitic fraction is grey to black without the multicolour intercalations of the northern outcrops.

Further south along the Ríos Zula, Silante and San Pedro, the Punín subdivision is entirely grey to black in colour. The quartzites are fine- to medium-grained, poorly sorted, and dominated by smoky quartz clasts with subordinate blue quartz.

North of the Punín inlier there is a quartzite outcrop near San Jose de Poaló ascribed to the Punín subdivision, whilst a further 180 km to the north the basement inliers of Ambuquí (the Ambuquí subdivision) comprise quartzites and black phyllites of similar aspect to the type area. It is probable that the Guamote division forms a continuous belt covered by the Cenozoic volcanics of the Inter-Andean Valley.

2.2.2 Tectonics of the Guamote division

Over the Riobamba-Cuenca region the characteristic tectonic feature of the division is the flatness of tectonic structures manifested as cleavages and sheared fold limbs; this is in marked contrast to the structures east of the Peltetec fault.

Over the north of the Riobamba-Cuenca belt of inliers, a gently-dipping (usually to E) penetrative first cleavage (S₁) can be identified subparallel to bedding. South of Palmira this is in turn cut by a gently-dipping second crenulation cleavage (S₂) roughly parallel with the first. Over the entire area there are 70°-trending, late, upright, open-to-close folds associated in places with a subvertical crenulation cleavage; thus, steep dips of bedding/S₁/S₂ may be encountered. These late structures are believed to be related to an event which also affected the Cretaceous cover sequences.

Both S₁ and S₂ cleavages are axial planar to minor folds, many of which show overall tectonic transport westwards (“Z”-form looking south, “S” looking north). At river outcrops 200 m E of Punín, small “ramp” structures in quartzites indicate a similar sense of movement.

Along the Pan-American highway south of Guamote, there are tectonic lenses of quartzite within slates, indicating an E-W stretching axis along the first cleavage.

The tectonics are complex in the Ambuquí subdivision but the main section along the Pan-American highway indicates E-dipping thrust sheets with overall westward movement.

2.2.3 Age of the Guamote division

The Guamote division is cut by the Pungalá pluton, dated by the project at 42 Ma (3). The division is unconformably overlain by the Maastrichtian (ca. 70 Ma) Yunguilla Formation of Bristow et al. (1975) and is tectonically part of a metamorphic complex with Jurassic palaeontological, igneous and metamorphic ages (this volume).

2.2.4 Interpretation of the Guamote division

The lithologies are of shallow-water, continent-derived sediments, whilst the tectonics indicate westward thrusting. Future studies may indicate that the Cebadas and Guasuntos subdivisions are one and the same, but tectonically repeated.

The tectonics almost certainly relate to the Peltetec “collision”, and it has been suggested that the Guamote division corresponds to passive margin sediments of the colliding western (Chaucha-Arenillas) continental plate (Aspden et al., 1988). However, the blue quartz in the Guamote sediments could be derived from the Tres Lagunas granite further east (see 2.6.1), in which case the Guamote division could represent a late-collisional molassic trough following ocean-closing.

2.3 The Peltetec Fault

This is an important new tectonic line through Ecuador which separates the Guamote and Alao divisions of the metamorphic basement. Recognition is twofold:

- (a) As a neotectonic lineament on imagery from Patate to Cuenca, particularly along the Río Chambo. In the field this lineament marks a neotectonic fault, which at Penipe and other localities shows downthrow to the west of upper Cenozoic volcanics against metamorphic basement. In this respect the Peltetec fault can be interpreted as the main eastern fault of the Inter-Andean Graben.
- (b) When this lineament is traced in the field over the metamorphic basement it is seen to coincide with an older fault, which divides the continental Guamote division from the oceanic Alao division and their corresponding horizontal and vertical tectonic domains, and marks the line of the Peltetec ophiolitic subdivision.

The Peltetec fault is important in that it represents rejuvenation of a fundamental ophiolitic line which has been interpreted as a suture (1, 2, 3; Aspden et al., 1987; Aspden and Litherland, 1987; Aspden et al., 1988).

2.4 The Alao division

2.4.1 The Peltetec (*ophiolitic*) division

This occurs in inliers along a narrow belt, 1-2 km wide, bounded to the west by the Peltetec fault, manifested in the basement as a tectonic contact with rocks of the Guamote division. The subdivision can be traced from the Penipe inlier in the north to the Río Zula in the south, a distance of about 85 km.

There are five accessible sections (2) across the subdivision; the first three contain igneous ophiolitic rocks which have been studied petrographically (4) and geochemically (3):

- (a) **Penipe:** along the track south to Río Blanco there are fine-grained, cleaved, green metabasalts, black phyllites (volcaniclastic mudstones), black serpentinites with magnesite veins, pyroxenites and hornblendites.
- (b) **Río Alao:** along the road before Peltetec village there are ophiolitic outcrops and loose blocks and further outcrops up the hill to the north.

Many of the samples are of altered basalts, microporphyratic in places. Alteration is moderate: to quartz, albite, carbonate, sericite, chlorite and epidote: compatible to reaction with heated seawater. There are also hydrothermally brecciated and strongly schistose varieties; dolerites occur with spillitic alteration.

The plutonic rocks can be divided into those in which alteration has destroyed almost all the primary constituents and those in which augite is substantially unaltered. Among the former group are rocks in which primary grain boundaries are preserved indicating static alteration to minerals such as brucite, tremolite-chlorite, quartz-hematite-sericite (after plagioclase), carbonate and albite. Plutonic rocks with deformed fabrics include foliated tremolitic serpentinites and sheared gabbros rich in brucite (after pyroxene) and periclase (after feldspar).

The other group of less-altered plutonic rocks comprise melanocratic olivine gabbros and peridotites. In general plagioclase is replaced by pseudomorphs of brown, sub-opaque, cryptogranular material, and olivine by pseudomorphs of serpentinite or chlorite-quartz. Pyroxene (augite) has resisted alteration. One specimen shows zones of penetrative comminution probably due to forceful gas penetration and resultant fluidisation suggesting interaction with later, near surface, eruptive activity (4).

Sedimentary rocks at Alao include cherts, black phyllites and volcanoclastic basaltic breccias.

- (c) **Río Huarguallá:** here along the irrigation canal is the best section of the Peltetec subdivision. Guamote division semipelites are followed eastwards by tectonic slices of Tres Lagunas-type granite with blue quartz (see 2.6.1); then by 15 m of E-dipping serpentinite, sheared towards the base; followed by olivine gabbros/olivine pyroxenites, spillitic basalts, cherts and black phyllites. Most lithologies can be seen to be tectonically isolated in the form of a *mélange*. Basaltic sedimentary breccias were also noted (4).
- (d) **Guamote-Atillo road:** here the *mélange* is dominated by black and maroon cherts, slices of blue quartz granite with megacrystic smoky K-feldspar, and variably silicified fine-grained sediments. No ophiolitic igneous rocks were noted.
- (e) **Río Zula:** along the well exposed road to the south of the river the subdivision comprises a *mélange* of sheared and variably silicified grey and greenish fine-grained rocks and slices of blue-quartz Tres Lagunas-type granite, followed eastwards by a *mélange* of mudstones and greywackes with chert clasts.

2.4.2 The Maguazo (turbiditic) subdivision

This occurs in inliers along a 5-10 km wide belt from San Jose de Poaló in the north to the Río Paute, a distance of about 200 km. Exposed sections occur at San Jose de Poaló, Río Blanco de Patate, Río Patate, Río Blanco de Penipe, Río Alao, Río Huarguallá, Río Atillo, Río Zula and Río Paute. The subdivision exhibits tectonic contacts with the Peltetec subdivision in the west and with the Alao-Paute subdivision to the east along the San Antonio fault.

The subdivision is dominated by a greywacke (turbidite)/andesite sequence. The turbidites are fine-grained and siliceous at the Río Maguazo (Alao Valley) but more volcaniclastic at Quebrada Totora Yacu (Paute Valley), in both cases graded bedding is preserved. The andesites are typically massive rocks with some greenstone alteration and contrast with the cleaved greenstones of the adjacent Alao-Paute subdivision. Other lithologies include green metatuffs, ferruginous in places; black slates; dark or pale marbles (Huarguallá, Zula, Río Blanco de Patate, Paute); reddish, fine-grained orthoquartzites (Atillo, Alao) and cherts. The red chert blocks of the Río Jadán (Paute Valley) are particularly noteworthy, whilst black and white cherts are exposed along the Río Zula alongside fine siliceous metavolcanics. Detailed mapping in the Alao Valley (2) shows a folded right-way-up sequence, at least 3 km thick, comprising andesites/turbidites followed by the main andesitic belt, overlain by the turbidites of Río Maguazo. A feature of the subdivision is the general absence of *mélange* type tectonics typical of the Peltetec belt to the west.

2.4.3 The Alao-Paute (greenstone) subdivision

This is essentially a greenstone sequence which occurs in inliers along a 10-25 km wide belt from the Río Pastaza in the north to Río Paute - Sigsig, a distance of about 200 km. Other outcrops may be present in the north near Ambuquí (Pacheco subdivision) and in the south near Fierro Urco and Quilanga. The subdivision is bounded to the west by the Maguazo subdivision along the San Antonio fault, and to the east by the Loja division along the Baños front. Studied sections include the Río Pastaza, Río Alao, Río Palora (headwaters) and the Río Paute.

Meta-andesites, which now form part of the Alao-Paute subdivision, had previously been recognised by Sheppard and Bushnell (1933), Bristow (1973) and Herbert (1977), and were included within the (now disbanded) Paute “Group” of Baldock (1982).

The main lithology of the subdivision is an andesitic greenstone, massive to sheared and schistose in the north where the tectono-metamorphic overprint is greater; whilst in places preserving relict igneous minerals/textures in the south. The main mineralogy is of greenschist facies: chlorite + albite + quartz + epidote $\pm$ biotite $\pm$ actinolite.

Subordinate lithologies include greenschists (metatuffs), pelitic and graphitic schists and minor dark marbles. Agglomerates are a feature of outcrops along the Río Paute west of Gualaceo. There are unconfirmed reports of blue quartz gneisses of Tres Lagunas metagranite-type in the Alao hills and west of Gualaceo; if these are present, tectonic contacts against Alao-Paute greenstones would be expected.

2.4.4 The El Pan (schist) subdivision

This lithotectonic subdivision corresponds roughly to the El Pan schists of Bristow (1973); it is enclosed by the Alao-Paute subdivision.

The massive meta-andesites typical of the Alao-Paute subdivision are wanting and the unit is dominated by quartz-calcite-chlorite greenschists, quartz-sericite phyllites and graphitic schists with lesser quartzites, quartz-albite-epidote-chlorite schists, actinolite-chlorite schists, black marbles, epidote rich calc-silicates and clinozoisite-tremolite rocks.

2.4.5 The Pacheco (greenstone) subdivision

These rocks are exposed along the Pan American highway in the Chota Valley, near Ambuquí, in the north of the country. They are in tectonic contact with the Ambuquí subdivision (Guamote division). The greenstones are of basaltic affinity but are provisionally grouped with the Alao division owing to the lack of other ophiolitic vestiges. The tectonic contact probably represents the Peltetec fault, or a branch of the same structure.

2.4.6 Tectonics of the Alao division

With the exception of the western outcrop of the Peltetec subdivision in the Huarguallá Valley which dips gently to the E, the Peltetec rocks are subvertically foliated, in marked contrast to the Guamote division semipelites to the west. At good exposures the shear planes can be seen refracted around competent bodies within the *mélange*.

The rocks of the Maguazo subdivision exhibit no such *mélange* features. In the Río Maguazo region of the Alao Valley, a first phase syncline can be elucidated using way up indicators in the graded turbidites; the fold is tight to isoclinal, upward-facing with steep axial plane and plunges gently to the S. A similar fold can be seen in the turbidites of Quebrada Totorá Yacu along the Río Paute Valley, 120 km to the south, and it is quite probable that there is a common D1 synclinal axial trace within the Maguazo subdivision which essentially determines its outcrop.

In the Alao Valley the change from Maguazo to Alao-Paute rocks across the San Antonio fault is marked by the appearance of a penetrative, steeply-dipping S2 schistosity in the latter rocks coupled with higher metamorphic grade within the greenschist facies, i.e. development of schists. In the same rocks along the north side of the Pastaza Valley, the same S2 schistosity is axial planar to tight D2 folds of bedding/S1 verging east with subhorizontal axes. The pre-D2 disposition of bedding/S1 would seem to be subhorizontal over this sector, indicating an early D1 nappe phase. It is unclear whether the Maguazo D1 corresponds to D1 or D2 in these Alao-Paute rocks; what is clear that the San Antonio fault marks a change in tectonic domain. Further south along the Río Paute a steeply-dipping penetrative S1 cleavage is present throughout; there is no major D2 overprinting.

2.4.7 The age of the Alao division

Various intrusives which cut the Alao division have been dated by the K-Ar method. Dates from the Magtayán granodiorite (3, Kennerley, 1980) are in the region of 70-80 Ma; those of the Tampanchi complex (4), 60-80 Ma; those of the Amaluza pluton, 40-50 Ma. Phyllites from the division have been K-Ar dated at 90 Ma (Kennerley, 1980) and meta-andesites at 100-140 Ma (3). All these are minimum dates.

It is clear that the Maastrichtian Yunguilla Formation (Bristow, 1973) unconformably overlies the Alao division, though the presence of andesitic lavas in this sequence was a factor which led to its correlation with the metamorphic basement (Bristow, 1973).

Float block samples from the Río Jadán (Paute Valley) of Maguazo subdivision calcareous black phyllite and chert have yielded Callovian-Oxfordian (156-169 Ma) palynoflora (3), in particular *Tubotuberella eisenackii*. The samples contain reworked early Ordovician acritarchs.

Samples from outcrops of Maguazo and Alao-Paute metasediments along the Paute Valley confirmed the Jurassic palynoflora (4) and also suggested the presence of Lower Palaeozoic acritarchs.

2.4.8 Interpretation of the Alao division

The lithologies of the Peltetec subdivision form an ophiolitically-related suite. The basalts and sediments could represent the upper part of the oceanic crust; the dolerite, intermediate levels; the plutonic rocks, sub-crustal magma chambers. Other rocks could represent alteration and deformation along shear zones within the *mélange*. Thus, the Peltetec division has been interpreted as a fundamental collision suture (Aspden and Litherland, 1987; Aspden et al., 1988).

The Mid/Late Jurassic Maguazo and Alao-Paute subdivisions have been interpreted as forearc and island arc belts respectively (Aspden et al., 1987) and, along with the Peltetec subdivision, forming an oceanic “terrane” sandwiched by the Peltetec fault and Baños front.

2.5 The Baños Front

This is another recently-discovered fault fundamental to the understanding of the Cordillera Real metamorphic complex. The structure takes the form of a hiatus, first noted east of Baños, which marks a change in lithotypes and metamorphic grade albeit across varying widths of steeply-dipping, strongly deformed rocks.

From the Río Pastaza (Baños) to the Río Upano, the Baños front is marked by the eastward appearance of pelitic schists, gneisses and granites of the Loja division against Alao-Paute greenstones. Further south, along the Río Paute, however, the lithological changes is not noteworthy: two greenstones sequences are juxtaposed (Alao against Salado).

Further south, around the Sigsig sector, the Baños front is again marked by a lithologic change within a 5-7 km-wide mylonite belt affecting both the Alao-Paute greenstones and the Tres Lagunas granite. Dips are to the west and both mineral lineations and sense of movement indicators suggest eastward thrusting. Further north at Baños, however, the lineations plunge SW at shallow to intermediate angles, and there is a clear suggestion of a dextral component of movement along the front.

To the north of Baños the front is tentatively projected under the Cenozoic cover rocks to divide the Ambuquí and Monte Olivo basement areas. In the south it is thought to follow the line of the Las Aradas fault, bounded to the east by outcrops of the Tres Lagunas granite, and to the west, at Quilanga, by ?Alao-Paute greenstones.

2.6 The Loja Division

2.6.1 The Tres Lagunas (granitic) subdivision

Biotite granites and granite gneisses, in places containing blue quartz, muscovite and garnet, crop out east of the Baños front for considerable distances. Such rocks had previously been noted at Tres Lagunas, near Saraguro, (Kennerley et al., 1973), around Peggy Mine (Harrington, 1957), and Papallacta (P. Duque, personal communication) but the present studies have now traced two main belts: Oyacachi - Río Palora; and Sevilla de Oro - Peruvian border; though with no photogeological expression between traverses interpretation is necessarily conjectural. The granite thus represents another important new component in the geology of the Cordillera Real. North of Oyacachi the belt is probably manifested as the Monte Olivo pegmatites, but between Río Palora and Sevilla de Oro, i.e. along the Río Upano and Río Paute traverses, there is little or no evidence for the granite. The best accessible outcrops occur at Peggy mine, others at Agoyán and around the Malacatus basin.

Small outcrops of Tres Lagunas-type rocks occur, strongly sheared, west of the Baños front within the Peltetec subdivision (see 2.4); such outcrops could be crucial in any plate tectonic interpretation.

Considerable specialised work has been done on this subdivision, both in terms of chemical analyses (3, 4) and petrography studies by Atherton (2), Dangerfield (3) and Fortey (4).

The granites of the Tres Lagunas subdivision invariably show evidence of deformation and metamorphism, ranging from incipient alteration in massive rocks with preserved igneous textures, to the formation of gneissic and mylonitic granites and augen gneisses. Tectonic contacts with the country rocks have been noted and on Map 2 most contacts are interpreted as such. Typically belts of highly-strained rock are interspersed with less-strained suggesting a series of ductile faults (imbrication). Such features are well-exposed over the Tres Lagunas area.

The more massive granites are typically medium- to coarse-grained with megacrysts of grey, smoky, alkali feldspar; blue or grey quartz; pale, cream-coloured plagioclase; and biotite (up to 1 cm across), with a restricted monzogranite-granodiorite composition; hornblende is absent. No calc-alkaline associates, e.g. diorite or gabbro, have been noted. The blue quartz is found even in the mylonite varieties and may be due to crystal lattice deformation. However, it must be pointed out that granitoid rocks of the adjacent Azafrán subdivision are similarly deformed yet never exhibit this quartz colouration.

Garnet is widespread in the granites, up to 30% in modal composition, and a belt of garnet granite can be mapped between Oyacachi and Papallacta; cordierite has been reported. Muscovite is fairly common; zoisite and chlorite are normally present as are trace amounts of apatite and opaques.

Xenoliths are relatively rare, but greenschists of metavolcanic/volcanoclastic origin, quartzite and “aplitic” variants of similar composition to the host have been observed. Partially assimilated semi-pelitic xenoliths were noted in river blocks above the Agoyán Falls (Río Pastaza); there is a pre-granite phase of folding. These blocks also exhibit amphibolite dykes of syn-intrusive basalt/dolerite affinity which have been noted in other units of the Loja division (see 2.6.4). The marginal foliation in the dykes is parallel with the augen foliation of the metagranite. The well-photographed Agoyán Falls exhibit what appears to be an amphibolite dyke cutting Tres Lagunas granite.

Late magmatic features include the formation of (smoky) perthite mega-crysts, muscovitisation, epidote, sericite-zoisite alteration of feldspar, recrystallisation of biotite, and growth of brown tourmaline. Secondary granoblastic quartz fabrics are widespread accompanied by partial replacement of feldspar and mica by quartz.

The mylonites involved the growth of a new generation of biotite together with muscovite, epidote, calcite and chlorite. Mylonites are cut by undeformed veins of K-feldspar pegmatite and quartz-feldspar- tourmaline.

Tourmaline pegmatite and quartz-muscovite-tourmaline “greisen” are common east of Gima, and north of Catamayo on the new Loja-Saraguro road. They are also found to the west of the Malacatos basin in the Loma del Inca sector. North of Oyacachi similar tourmaline-bearing rocks are associated with the Monte Olivo pegmatite belt (4). This comprises a narrow (1-2 km) belt of gneissic and massive aplogranites, pegmatites and pegmatised schists with megacrysts of perthite, tourmaline, muscovite, ilmenite and green zoisite.

Chemical analyses show the granites to be high in quartz and falling into the “S”-type field of Chappell and White’s (1974) K_2O/Na_2O diagram (3, 4); Rb-Sr studies indicate a high initial $^{87}Sr/^{86}Sr$ ratio (>0.71)

2.6.2 The Agoyán (schist and paragneiss) subdivision

This unit of metamorphic pelitic and semipelitic rocks extends from the Colombian border to the Río Upano, south of which it is replaced as “host” to the Tres Lagunas granite by the Chigüinda semipelites except for a single sector north of Loja. The most accessible outcrops are along the road just east of the Agoyán tunnel near Baños; others occur near Monte Olivo and Papallacta.

Lithologies are dominated by medium- to coarse-grained muscovite-garnet schists and paragneisses, with garnet crystals reaching over 1 cm in size at Agoyán and Río Palora; biotite, chloritoid and chlorite may also be developed. Thin fine-grained orthoquartzites may be present and certain sequences are semi-pelitic in character; black graphite schist may occur. Near Monte Olivo there is a belt of medium-grained metapsammites, with significant feldspathic component.

The paragneisses are medium-to coarse-grained rocks with an increased quartz-feldspathic component. In the north, east of San Gabriel and Monte Olivo, they can be differentiated from the schists. Float blocks in the Río Chalpi de Papallacta indicate small concordant and sheared granite veins indicative of incipient migmatisation. Some of the gneisses east of the Baños front toward Agoyán contain blue quartz veins.

2.6.3 The Chigüinda (semi-pelitic) subdivision

Semipelitic rocks dominate the metamorphic complex of the southern Cordillera Real forming a belt 10-30 km wide from the Peruvian border north to the Gualaceo-Limón road; this belt is host to the Tres Lagunas granites and had previously been studied by Kennerley (1973) and Trouw (1976). Further north, rocks similar to those of the Chigüinda subdivision have been identified in the Río Upano and over the páramos of Antisana where they crop out extensively over the Cuyuja flat belt in the form of a nappe sheet. Good accessible outcrops occur along the Gualaceo-Limón, Loja-Zamora, Sigüig-Chigüinda and Loja-Catamayo roads.

Lithologies comprise a monotonous sequence of generally low-grade, impure, grey quartzites; metasilstones; grey to black phyllites, graphitic in places; slates and occasional greywackes. Greenish metavolcanic rocks are very rare. Bedding planes are preserved but sedimentary structures are not. Apart from sericite and chlorite, biotite and garnet have been noted particularly over a locally flat-lying “schistose” sector along the Gualaceo-Limón road (see also Trouw, 1976), whilst staurolite has been identified in a sample from the Catamayo-Loja road.

2.6.4 The Monte Olivo (amphibolitic) subdivision

Basaltic actinolitic amphibolites occur as a small belt west of Monte Olivo and outcrops along the road indicate ?sedimentary intercalations with the adjacent metapsammites, suggestive of original basalt flows.

Further south, along the Río Anatenorio, similar amphibolites crop out, but these are clearly discordant to the stratification in the adjacent Agoyán schists, though deformed and metamorphosed with them. It is suggested that these basaltic/doleritic bodies are the same as those found in the adjacent Tres Lagunas granite, being syntectonic and synintrusive. Other “discordant amphibolites” have been noted cutting the Agoyán subdivision along the Baños, Papallacta and Oyacachi traverses though these are too small show on Map 2.

2.6.5 The Sabanilla (gneissic) subdivision

This is a suite of gneisses and schists which forms a 10 km wide belt north from the Peruvian border for 150 km, bounded by tectonic contacts with the Chigüinda subdivision to the west and the Zamora division to the east. Good accessible outcrops occur along the Loja-Sabanilla-Zamora and Loja-Zumba roads and along the track to Pico Toledo.

The subdivision comprises foliated, possibly syntectonic, metaplutonic rocks of granodiorite to tonalite composition associated with metasediments which contain garnet, staurolite, sillimanite and kyanite: a medium-to-high grade metamorphic assemblage. Hornblende-biotite amphibolites are also relatively common especially within the plutons and their form indicates original dykes.

The plutons are tectonically foliated and contain gneissic xenoliths and muscovite-biotite streaks. Migmatitic rocks have been observed (see also Trouw, 1976) but these are not regionally developed and may relate to contact zones.

2.6.6 Tectonics of the Loja division

North of Baños, the Loja division rocks west of the Llanganates fault are characterised by a subvertical or W-dipping, Andean-trending, second schistosity, S₂, similar to that west of the Baños front; mineral lineations are horizontal (Andean-trending) or S-plunging with low to moderate angle. Narrow belts of flat tectonic foliation do occur, e.g. north of the Río Antisana, but these essentially are monoclinical in form. East of the Llanganates fault, however, rocks of the Agoyán, Tres Lagunas and Chigüinda subdivisions, isolated by bodies of skarn and serpentinite (see 2.9), form the upper tectonic levels of the great Cuyuja flat belt of nappes tectonically overlying rocks of the Salado division; there are even thin 1 m tectonic intercalations of Tres Lagunas granite within this nappe sequence within which horizontal D₂ folds with wavelength up to 30 m were noted. Thus, from the headwaters of the Río Cosanga to the Sub-Andean front, the Cosanga Valley is flanked by flat-topped hills comprising the Chigüinda subdivision with subhorizontal S₂ foliation and axial planes; in total the Cuyuja flat belt is 20 km wide including the zone of the open-to-close Urcucocha synform, which occurs from Sara Urco to Urcucocha and is marked by skarnfield klippen (2.10).

South of Baños the Loja division is dominated by an eastwards (tectonic) progression from Tres Lagunas granite, through Chigüinda semi-pelites to Sabanilla gneisses. All these units are cut by an Andean-trending D₂ tectonic foliation which is generally steeply-dipping to the west and refolds an Andean-trending D₁. A limited flat foliation belt occurs close to the Baños front in the west but, as in the north, it is monoclinical in gross form. The fault contact marking the eastern margin of the Sabanilla subdivision against the Zamora division is shallow-dipping to the west.

The presence of flat on W-dipping foliations, and subhorizontal mineral lineations indicates eastward thrusting with a horizontal (transcurrent) component.

2.6.7 Age of the Loja division

Kennerley (1973) considered the semipelites of the present Chigüinda subdivision to be Palaeozoic in age on the basis of their supposed continuity with metamorphic rocks in Peru overlain by Jurassic sediments (Gerth, 1955).

The Agoyán subdivision has provided the “oldest” K-Ar ages of the Cordillera Real. Project K-Ar studies of Agoyán gneisses from Río Chalpi de Papallacta yield biotite dates of ca. 881 and 844 Ma; hornblende dates of ca. 342 and 306 Ma and a muscovite date of ca. 74 Ma (4). An amphibolite dyke nearby gave ca. 365 Ma (3). Sm-Nd studies on the Papallacta garnet gneiss (9 samples) gave 1744 ± 787 Ma (MSWD = 73.3) (4). Evernden (1961) reports a single K-Ar date of 417 Ma from the schist at Agoyán but muscovite/chlorite date from the same sector yield 60-90 Ma ages (3; Feininger and Silberman, 1982; Herbert and Pichler, 1983).

20 samples of the Tres Lagunas granite (11 from the Tres Lagunas sector, 9 from near Malacatus) give an age of 200 ± 12 Ma (MSWD = 169.1) on an Rb-Sr plot (4). Eight K-Ar ages from Tres Lagunas samples range 50 to 90 Ma (3, 4).

Sabanilla subdivision orthogneisses from Valladolid give a 10-point Rb-Sr errorchron of 357 ± 99 Ma, whilst those from Sabanilla give a 10-point plot of 198 ± 45 (MSWD = 25.3) (4). An earlier 8-point Rb-Sr plot for Sabanilla gneisses gave 233 ± 51 Ma (MSWD = 174.4) (2). 11 K-Ar dates from Sabanilla are in the range 65 to 87 Ma (3, 4), with biotite ages older than muscovite; but one hornblende date gives ca. 130 Ma (3). Previously Kennerley (1980) reported K-Ar ages of 70-80 Ma.

2.6.8 Interpretation of the Loja division

The Loja division essentially comprises the Tres Lagunas granite and its envelope rocks. The characteristics of the granites; restricted composition, presence of garnet and cordierite, high initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, set them apart from other I-type (igneous type) batholiths of the Andes, and indicate the presence of S-type (sedimentary type) plutons generated from within the continental crust (Chappell and White, 1974); the granites plot in the S-type field on their $\text{K}_2\text{O}/\text{Na}_2\text{O}$ diagram.

The envelope rocks are essentially comprised of continent-derived metasediments as indicated by the pelitic and semipelitic Agoyán and Chigüinda subdivisions; there were however basalt flows and syntectonic mafic dykes. The Sabanilla subdivision may represent a lower crustal segment. Thus, the continental Tres Lagunas granite is associated with continental sediments.

Field evidence in the forms of folded metamorphic xenoliths indicates that the Tres Lagunas granite intruded continental crust, the regional representatives of which, the Agoyán and Chigüinda subdivisions, give the oldest dates of the cordillera: Carboniferous to Precambrian. Whilst such dates cannot be altogether relied upon and require confirmation, a case can be made to interpret the Loja division as pre-Jurassic continental crust intruded at ca. 200 Ma by the Tres Lagunas granite; the 50-90 Ma K-Ar resetting can be explained by Andean collision events during that time (see 2.11).

2.7 The Salado division

2.7.1 The Azafrán (plutonic) subdivision

A variably deformed plutonic phase at Azafrán, on the Río Pastaza (Baños-Puyo) road had previously been noted (Sauer, 1958, Kennerley, 1971) and previous maps had shown a small body straddling the Río Pastaza. The present studies have extended this plutonic phase north to the Colombian border, a distance of ca. 250 km and south to the Río Upano, a distance of ca. 100 km, thus providing another batholith chain of the Cordillera Real, along with those of Tres Lagunas and Zamora. Accessible outcrops occur along the Baños-Puyo road and the road to La Bonita.

Along the Colombian border the Azafrán subdivision is represented by the Chingual and Sacha plutons which can be traced as one unit east of Monte Olivo and as imbricated belts in the Ríos Salado and Oyacachi. Over this northern area, undeformed to gneissic, grey, coarse-grained granodiorite-tonalites are typical, with subordinated diorites; dolerites, hornblendites and gabbros are rare, although a pegmatitic gabbro forms a marginal zone to the Chingual pluton along the Colombian border. Biotite megacrysts, up to 1 cm across, provide a spotted granodioritic rock; hornblende may be present; deformed or undeformed mafic xenoliths are common. Granites are rare, the only occurrence being the Río Cedro pluton along the Río Oyacachi. Along the Río Diviso, a tributary of the Salado, diorites show intrusive contacts with feldspathic porphyries, mappable on a 1:500000 scale.

There are no outcrops along the Papallacta-Baeza road and the Río Cosanga, over which the plutonic phase is probably covered tectonically by the Cuyuja flat belt of nappes. Further south, the subdivision reappears in the Chalupas, Mulatos and Pastaza (Azafrán) rivers and underlies the páramos east of Cerro Hermoso. Rocks are similar to those in the north; granite/quartz-monzonite is the composition of the “Azafrán pluton” of Sauer (1958) and Kennerley (1971) along the Pastaza, but is absent elsewhere, whilst west of Río Verde, diorites and metadiorites form a more extensive plutonic belt; the change from undeformed to gneissic belts along the Pastaza section suggests imbricate thrust tectonics. Calcite-quartz-biotite-sulphide veins are concordant to the shears and all rocks are cut by later discordant epidotic shear veins. Late, undeformed, quartz-monzonite dykes are common over the Llanganates area and probably relate to the Azafrán igneous phase.

South of the Río Pastaza the geological map of the Río Palora is based largely on float block data including many massive-to-gneissose, granodiorites and diorites of Azafrán-type. Further to the south the new road from Macas to Guamote cuts through the northern contact zone (granite, pegmatite, dolerite) of an undeformed granodiorite-monzogranite body as evidenced in river float blocks. This pluton has been included with the Azafrán subdivision on lithological grounds; although gneissose rocks are wanting.

The extensive, poorly-accessible Condué granite, discovered in the extreme north of the area, is a pale or pink, undeformed, homogeneous, coarse-grained, leucocratic, biotite monzogranite. It is tentatively assigned to the Azafrán subdivision on Map 2A, presumably a post-tectonic phase.

2.7.2 The Upano (volcano-sedimentary) subdivision

This is a metamorphosed volcano-sedimentary sequence geographically related to the Azafrán plutonic chain and forming its host rocks. The subdivision extends from the northern Cordillera Real south to the Cuenca-Limón road, south of which it wedges out along the sub-Andean belt over an area where the Upano volcanics exhibit many of the “continental” aspects of the adjacent Misahuallí subdivision. Accessible exposures occur along the Guamate-Macas road (Río Upano); west of Baeza, on the road to Papallacta; and on the Cuenca-Limón section. Those rocks of the subdivision lying to the east of the present sub-Andean fault had previously been ascribed to the Palaeozoic Pumbuiza Formation (Sauer, 1958) or the younger Margajitas Group (Baldock, 1982).

North of the Río Pastaza, andesitic greenstones and green or pale schistose metatuffs are common, associated with volcanoclastic rocks, greywackes, graphitic and pelitic phyllites, and thin marbles. Such an affiliation can be observed west of Baeza and along the Río Oyacachi west of the Río Santamaría. Further west within the same sector, subunits consisting largely of graphitic schists and pelitic schists have been delimited on Map 2A. The latter rocks may contain garnet, chloritoid, and kyanite within the greenschist facies (P. Duque, personal communication) and may resemble the Agoyán schists of the Loja division. The volcanoclastic greywackes are grey to black in colour and may be characterised, microscopically, by the preservation in individual clast of volcanic textures with opaque “peppering” which may remain in the metamorphic mosaic after quartz grain recrystallisation.

Further south the metasedimentary component is more dominant along the Río Upano, but the greenstones return to prominence along the Río Paute where they are difficult to distinguish from those of the adjacent Alao-Paute subdivision. These metavolcanics exhibit, petrographically, a varying tectonometamorphic overprint which in many cases destroys the original texture (e.g. feldspar phenocrysts), and are thus similar to the Alao-Paute greenstones; local epidotisation is common and epidote-rocks have been noted.

2.7.3 The Santa Bárbara (gneissic) subdivision

These gneisses enclose the Chingual pluton of the Azafrán subdivision along the Colombian border, along the La Bonita road. The gneisses are fine- to-medium grained, banded, and biotite rich ($\pm$ hornblende) and could be derived from a calcareous tuff protolith. No migmatites have been noted over this ground where Salazar et al. (1986) have suggested the presence of an extension of the Colombian Precambrian Garzón massif (Kroonenberg, 1982).

2.7.4 The Cerro Hermoso (carbonate) subdivision

Cerro Hermoso, in the heart of the Llanganates, was first studied by Sauer (1958) who described the lithologies and proposed a thrust sheet model, later supported by Vera and Vivanco (1983). Relatively detailed 1:10000 scale mapping by the project team (2) shows that the Cerro Hermoso succession is affected by one phase of simple upright folds and subvertical cleavage and contrasts strongly with the Cuyuja flat belt, along strike to the north, where tectonics are flat and where thrust sheet (nappe) models can be proposed.

The metamorphic rocks at Cerro Hermoso are unique to the cordillera in that they are both very well exposed over rugged glaciated terrain and also preserve way-up indicators (cross-bedding and sedimentary bottom structure) so that a local stratigraphy can be elucidated. This takes the form of basal muscovite-garnet chloritoid schists, metagreywackes and Azafrán metadiorites, overlain by 80 m of black schists and metagreywackes of Upano subdivision-type; pale, fine, muscovite-chloritoid metawackes with marbles and meta-conglomerates (10 m); followed by calcareous black schists, in places spotted with andalusite (40 cm); black marbles with shelly fragments with garnet chloritoid calc-schists (50 m); black calc-schists (10 m); and finally, at least 350 m of a weakly-metamorphosed banded calcareous sequence composed of black carbonates, with a partially recrystallised shelly fauna, slates and paler metapsammities which comprise the main summit. This same sequence forms a steeply-dipping, W-younging belt to the west of Cerro Hermoso from Río Pastaza to Río El Golpe.

Certain other carbonate horizons within the Salado division are also ascribed to the Cerro Hermoso subdivision on Map 2. One of these forms a 'marker' in the nappe pile of Cuyuja between the Loja and Salado divisions. Rocks are generally dark or pale marbles or calc-schists but in the Río Cosanga impure fuchsitic ?dolomite predominates.

2.7.5 Tectonics of the Salado division

In the north of the area the four subdivisions of the Salado division exhibit one or two common phases of tectonometamorphic overprint involving horizontal or vertical tectonic regimes.

The Azafrán plutonic phase everywhere exhibits subvertical shear zones and its outcrop pattern indicates the presence of tectonic repetition in the form of thrust imbrications. However, over the Cuyuja flat belt it is clear that units of the Upano subdivision along with serpentinites (see 2.9), skarn rocks (see 2.10.1), and units of the Loja division are thrust horizontally eastwards over the Azafrán-Cerro Hermoso steep belt in the form of a duplex roof thrust; the contact being well marked at the base of the El Placer skarnfield (2.10.1). The nappes of the Cuyuja flat belt are of local D2 age and bury the plutonic rocks of lower tectonic levels. Mineral lineations around Azafrán plunge gently to the south and microtectonic studies suggest a component of dextral movement (4).

Salado division rocks of the Cuyuja flat belt are juxtaposed against vertical units to the east across the sub-Andean fault. This vertical sequence comprises Salado and Zamora division basement along with Cretaceous Formations, which exhibit cleavage formation in pelitic units.

South of the Río Pastaza the Salado division rocks commonly show steep tectonic foliation, with only minor "flats", and evidence for eastward thrust sheet stacking.

2.7.6 Age of the Salado division

The best interpretation of the 10-point Rb-Sr errorchron for the Chingual metapluton gives an age of 156 ± 21 Ma (MSWD = 2.8) (2). The seven samples collected from the Azafrán granite/quartz-monzonite give an Rb-Sr isochron of 120 ± 5 Ma (MSWD = 2.4) (2) (initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.7046$). However, two samples of diorite from the Río Verde sector gave concordant hornblende-biotite K-Ar ages of ca. 128 Ma and ca. 173 Ma (2). Three K-Ar biotite ages from the granites are reset at 47-51 Ma, whilst three biotite K-Ar ages from the Chingual pluton are reset at 19-20 Ma and two K-Ar ages from the adjacent Sacha pluton reset at 25-34 Ma. Upano subdivision schists from the Papallacta-Baeza road give reset ages of 82 Ma (Kennerley, 1980), 59 Ma (Herbert and Pichler, 1983) and 54 Ma (Feininger and Silberman).

Kennerley (1971) and Vera and Vivanco (1983) regarded the Cerro Hermoso rocks as Cretaceous in age and there are reports of foraminifera (Vera and Vivanco, 1983); project thin sections also show poorly preserved faunas.

2.7.7 Interpretation of the Salado division

The division comprises the Azafrán calc-alkaline, I-type, plutonic phase and envelope rocks in the form of the Cerro Hermoso, Santa Bárbara and Upano subdivisions. The latter unit can be regarded as a new greenstone belt similar to that of Alao-Paute. Contacts with the pluton are mainly tectonic but the presence of veined and epidotised greenstones indicates proximity to the igneous phase. The andalusite and “spongy” garnets of Cerro Hermoso coupled with the regional evidence from the skarnfields (see 2.10.1) suggest that intrusion and tectonics were essentially contemporaneous.

The Salado division corresponds to a volcanic-plutonic arc situated close to the continental margin. Volcanos shed andesitic flows and tuffs in an unstable marine environment with turbidite-related subsistence and with period(s) of more stable shallow marine carbonate formation. The Salado igneous and sedimentary events appear to relate to the Mid/Late Jurassic; the Rb-Sr isochron of 120 Ma on the Azafrán granite is difficult to accommodate into any model. It is probable that the Salado “arc” was contemporaneous with the Zamora continental arc to the east (see 2.8.2).

2.8 The Zamora division

2.8.1 The Abitagua (plutonic) subdivision

This name is given to the chain of essentially undeformed calc-alkaline plutons, the approximate forms of which were known before the present project began. The three major bodies are, from north to south, the Rosa Florida, Abitagua and Zamora batholiths; all three intrude the essentially undeformed Misahuallí volcanic subdivision.

In the north the Rosa Florida pluton comprises grey quartz monzonites, porphyritic quartz-micromonzonites, pink quartz syenites and porphyritic quartz-microsyenites; fresh volcanic xenoliths are common. To the west lies the La Bonita metagranodioritic pluton, similar to that of Chingual.

Further south, the undeformed Abitagua batholith is essentially a biotite-monzogranitic pluton mixed with Misahuallí volcanics (Tschopp, 1953). On the Baños road the western 2 km exhibits K-feldspar megacrystic tablets whilst the remainder is essentially coarse grained and equigranular. Volcanic dykes and xenoliths are present in places. Along the Río Mulatos the western margin is of a xenolithic, medium-grained, hornblende-biotite granodiorite intruded by the younger, inner, shell, of K-feldspar megacrystic biotite granite.

Mapping into the great Zamora batholith in the extreme south of the sub-Andean zone of the cordillera has proved a far more extensive plutonic phase which includes the previously isolated Río Mayo batholith (Baldock, 1982). Compositions range from hornblende ($\pm$ biotite) diorites and quartz diorites to tonalites/granodiorites. True granites are rare. Porphyritic hornblende granodiorites are common west of Guaysimi.

2.8.2 The Misahuallí (volcanic) subdivision

This includes the upper “Misahuallí” pyroclastic facies of the Chapiza Formation (Wasson and Sinclair, 1927; Tschopp, 1953) and new occurrences intimately related to the Abitagua plutonic phase described above. Lithologies comprise usually undeformed green to dark grey or purple andesites and trachytes with greenish tuffs and agglomerates; basaltic pillow lavas crop out in the Río Paute east of Méndez.

In the north the Misahuallí subdivision occurs as the higher-level igneous facies of the Rosa Florida pluton in a southwards direction; the contact being a line marking the incoming of agglomerates, and green tuffs. West of the regional Cosanga fault, metamorphosed silicic volcanics, agglomerates and greenstones found associated with the La Bonita metapluton are also included in this subdivision. There are outcrops close to the Cosanga fault and float blocks in the Río Cofanes of a fine grained siliceous “cherty” volcano-sedimentary marker which may be hornfelsed and garnet-bearing.

Similar green and purple volcanics and agglomerates of Misahuallí-type are deformed west of the Cosanga fault in the Río Salado and float indication suggest a lateral transition (increasing sedimentary contents) into the Upano volcano-sedimentary subdivision of the Salado division.

Along the Río Mulatos and further north (Ing. O. Dávila, personal communication) the western margin of the Abitagua batholith is in intrusive contact with undeformed, pale, black, or pink, in places glassy, porphyritic silicic lavas associated with flow breccias and pyroclastics.

Further south the subdivision reappears south of Limón along the sub-Andean zone and forms the mantle to the Zamora batholith. The rocks are dominated by feldspar microporphyritic andesites and hornblende andesites. Dacitic lavas are also present and, in some areas, coarse volcanic breccias and agglomerates are common. Minor high-level subvolcanic intrusives are widespread and in many places, these are associated with zones of silicification, epidotisation or feldspathisation. These intrusives appear to consist largely of felsites and/or dacites but quartz and/or feldspar porphyries also occur; some may relate to younger Cretaceous/Cenozoic phases of volcanicity.

2.8.3 The Isimanchi (volcano-sedimentary) subdivision

To the east of Valladolid and in the Río Isimanchi east of Zumba, there are outcrops of low-grade volcano-sedimentary rocks lying to the east of the Sabanilla subdivision. Lithologies are steeply-dipping black and green phyllites, metatuffs and marbles; the latter vary from blue to off-white in colour and form a series of spectacular hills with karstic scenery. Contacts with the Sabanilla gneisses (Loja division) are tectonic, whilst eastwards toward the Zamora batholith the unit becomes hornfelsed and silicified; Isimanchi xenoliths are found within it.

2.8.4 Tectonics of the Zamora division

In the north the Zamora division rocks east of the Cosanga fault are essentially undeformed, whilst those to the west are affected at least by the late-Cenozoic event and probably by the Jurassic tectono-metamorphic event, e.g. the biotite mylonites along the Sofía fault which show vertical mineral lineations. South of the Río Salado, however, the Cosanga fault forms the natural boundary between the tectono-metamorphic Salado division in the west and the “cratonic” Zamora division in the east.

Further south, the position is similar, with the “cratonic” Zamora division lying to the east of the Méndez-Palanda fault; only the Isimanchi division is deformed.

2.8.5 The age of the Zamora division

A 17-point Rb-Sr isochron for the Abitagua granite, using samples collected at locations in the north and south of the batholith gave 162 ± 1 Ma (MSWD = 2.5) (initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.7046$) (2). Rb-Sr results from 31 samples collected from three sectors of the Zamora batholith give scattered plots. After the removal of high Rb/Sr late felsitic vein samples, the northern results give 220 ± 64 Ma (initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.7047$), whilst those for the Río Mayo sector give 144 ± 35 Ma (initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.7051$) (2).

24 K-Ar ages for the Zamora batholith and nine K-Ar ages from the Abitagua granite fall into the range 125 - 195 Ma (3, 4). Amongst these there are concordant hornblende and biotite ages of 152 Ma, 170 Ma, 173 Ma, 177 Ma and 186 Ma within the Río Mayo sector of the Zamora batholith and concordant ages of 153 Ma and 154 Ma in the NE sector of the same batholith.

Triassic bivalves were identified (3) from samples of dark grey calcareous siltstone from outcrops of a (?) xenolith of less-deformed ?Isimanchi subdivision within the Zamora batholith ca. 8 Km ESE of Zamora. The pectinaceans were either *Halobia*, *Dagnella* or *Entomonotis* and are therefore late Middle to Upper Triassic in age. They are most likely *Entomonotis richmondiana* and therefore possibly Norian.

Sinemurian ammonites were identified from the Santiago Formation (3) from the new road cutting through the Cutucú Uplift from Patuca to Santiago, thus confirming the Liassic age of this unit (Tschopp, 1953).

2.8.6 Interpretation of the Zamora division

The plutonic (Abitagua) and volcanic (Misahuallí) subdivisions can be regarded as an igneous association formed in the region of 150-190 Ma (Middle to Late Jurassic) and intruding Late Triassic (210-225 Ma) deformed Isimanchi rocks which may relate to the Lower Jurassic Santiago Formation (ca. 200 Ma) which crops out in the Oriente.

The plutonic rocks form an I-type calc-alkaline suite cutting and associated with continental volcanics. To the west across the “cratonic front”, the Cosanga-Méndez fault, there appears to be a facies transition with the Salado division plutonic-volcanic pair of similar age.

2.9 Pre-Cretaceous serpentinites east of the Baños Front

Aside from the discovery of ultramafic serpentinitic rocks along the Peltetec ophiolitic subdivision (2.4.1) and within the Cretaceous Tampanchi complex (2.11.3), outcrops and float blocks have also been found east of the Baños front over the pre-Cretaceous metamorphic basement. Sauer (1965) reported such lithologies as blocks in the Río Guachalá near Cayambe and as outcrops in the Río Mulatos. The first occurrence was confirmed by the project but no outcrops were seen in Río Mulatos. However, further examination of Sauer’s (1958) map and field data indicates that he traversed what is now referred to as the Río El Golpe/Niágara Grande or Paracayacu: a tributary of the Mulatos. Another discovery, in the Río Chalpi de Papallacta (P. Duque, personal communication) was also confirmed by the project. Colony and Sinclair (1932) reported outcrops and blocks in the Río Quijos west of Baeza, but only the blocks were confirmed. The following are the new serpentinite occurrences found by the project from north to south; see also Fortey’s petrographic descriptions (4) and chemical analyses (3):

- (a) **Small blocks of massive serpentinite:** Río Cofanes, near La Sofía, above Río Condué confluence.
- (b) **Outcrop of green, sheared, fuchsitic serpentinite,** 10 cm thick, in pelitic schists, along the road 100 m west of Río El Carmen near Monte Olivo. Other rocks with apple green fuchsite have been noted as small float blocks over the northern Cordillera Real.
- (c) **Large blocks of massive serpentinite and hornblendite:** Río Cariyacu, tributary of Río Oyacachi.
- (d) **Large blocks of massive serpentinite:** Río Quijos, upstream from confluence with Río Papallacta.
- (e) **Large blocks of massive serpentinite:** Río Huagrayacu, near Baeza: first noted by Ing A. Hirtz: almost certainly the source of the blocks in the nearby Río Quijos reported by Colony and Sinclair (1932).
- (f) **Small blocks of massive serpentinite:** Río Bermejo, south of Baeza.
- (g) **Small blocks of massive serpentinite:** Río Aliso, south of Baeza
- (h) **Outcrops of massive serpentinite:** Quebrada Soledad, south of Antisana. This forms a belt up to 30 m thick bounded by grey and black phyllites with thin quartzitic laminae.

- (i) **East of (h) there are massive and sheared serpentinite blocks and associated ultramafic schists** and asbestiform tremolite rocks in streams draining E and W from the Urcucocha skarnfield and a folded (synformal) serpentinite horizon is indicated on Map 2A.
- (j) **Further east from (i), in the sub-Andean reaches of the Río Cosanga**, large $6 \times 5 \times 5$ m blocks of massive serpentinite appear in the river. Map 2A interprets these as a sub-Andean serpentinite belt.
- (k) **Large blocks of massive serpentinites:** Río Mulatos, downstream from junction with Río Langoa.
- (l) **Blocks of massive serpentinite:** Quebrada de Los Incas, a tributary of the Río Muyo near El Triunfo.
- (m) **Outcrops of serpentinite and fresh mafic and ultramafic rocks** along the main road east of Zumba (Map 2B).

The field studies so far indicates that in the north of the Cordillera Real there is a thin massive serpentinite in the steep Loja division east of the Llanganates fault; a thin massive serpentinite related to the base of the Urcucocha skarnfield; and a thin massive serpentinite in the sub-Andean belt from Baeza to the Río Cosanga. All these serpentinites are similar in field appearance whilst petrographic studies (4) indicate a massive interlocking antigorite mesh, formed by static alteration of ultramafic rock, with later shearing and formation of magnesite and talc. It can thus be suggested that a common body was fragmented during thrusting to lie at different tectonic levels within the thrust/nappe complex. The massive serpentinites may have come from lenses of relatively undeformed rock within and between shear zones, as indicated by the Quebrada Soledad outcrops; they are not required to be obducted ophiolites.

It is noticeable that, with the exception of the Zumba serpentinites, all the occurrences lie north of the Río Pastaza over a region marked by nappe tectonics and the presence of the Salado division and associated skarnfields.

The Zumba ultramafic complex occurs in the extreme south of the cordillera and defines the fault which divides the Tertiary Zumba basin from the Isimanchi subdivision. Further east, near the junction of the Isimanchi and Mayo rivers, there are xenoliths in the Zamora batholith which include hypersthene gabbros and strongly chloritised and epidotised rocks which may relate to the Zumba complex

The Zumba lithologies (4) include serpentinites, quartz gabbros and a remarkable orthopyroxene-rich norite hornfels, in which the presence of hornblende and epidote suggests recrystallisation at moderate temperatures well below the solidus. It may thus be necessary to postulate the incorporation of parts of the Zumba ultramafic complex into the Zamora batholith before serpentinitisation

2.10 Skarn rocks

2.10.1 *The skarnfields of the northern Cordillera Real*

In 1986 the project geotraverse down the Río Mulatos identified skarn float blocks (1), and in 1987 a follow-up expedition was undertaken which successfully traced these blocks to outcrop: the El Placer skarnfield (2). Other skarnfields were discovered further north by the project at Urcucocha and Sara Urco (3), whilst mining company interest in the Mulatos discoveries led to the identification of a new field east of that sector. There is now a wealth of project information on these rocks including detailed petrography by Thompson (1), Williams (2) and Fortey (4); and chemistry (2, 3, 4). The occurrences from the north to south can be summarised as follows:

- (a) **A few blocks of epidote rock of skarn-type** were found in Quebrada Industria near Rosa Florida; no garnet-skarns were noted.
- (b) **A new skarnfield was discovered** on the western slopes of Sara Urco about 1 km from the summit. Garnet-rich and epidote-rock types are present with black marbles. The garnet-bearing types are calcic-magnetic skarns of essentially garnet - hedenbergite - ferrohastingsite - epidote - magnetite composition. Further east there are skarn blocks in the Río El Diviso (tributary of the Río Salado), and these may be derived from an undiscovered skarnfield.
- (c) **Skarn blocks occur in the Río Chalpi**, a tributary of the Río Oyacachi, and these are almost certainly derived from an undiscovered skarnfield south of Sara Urco, which should be present on a structural basis over the 3500 m contour. There are also blocks of metasomatised schists of volcanic or sedimentary origin; the latter are dominated by wollastonite (4)
- (d) **Large blocks of skarn occur in the Río Quijos** upstream from the confluence with the Río Papallacta. They are typically multicoloured calcic-magnetite skarns with pink (garnet-rich), green (epidote-rich) and black (amphibole- or magnetite-rich) zones cut by quartz or calcite veins.
- (e) **The Río Quijos blocks** may come from a northern extension of the Urcucocha skarnfield, discovered in 1988. Along the line of traverse this skarnfield is preserved as a synform of gently-dipping tectonic foliation and forms a small hill range about 200 m high. Rocks are massive, fine- to medium-grained epidote skarns which form the basal (150 m) and third (50 m) units in the local tectonic sequence separated by 80 m and overlain by 60 m of quartz-muscovite-biotite schist of metatuffaceous origin. In the field the epidote skarns can be seen to be derived from greenstones prior to the nappe/shearing event, which produced the subhorizontal foliation.

- (f) **The Inga skarnfield** was discovered at similar topographic levels across the Río Mulatos from the El Placer field (Ing. L. Torres, personal communication) and a tentative outcrop pattern is shown on Map 2A assuming a horizontal skarnfield.
- (g) **The El Placer field**, east of the Río Mulatos was the first to be discovered (2). Massive biotite-porphyroblastic amphibolitic greenstones are overlain by at least 160 m of subhorizontal tectonic slices identified at waterfalls at the headwaters of Río El Placer. Massive garnet-hedenbergite-ferrohastingsite-epidote-magnetite skarns and epidote skarns comprise about half the rocks, with tectonic intercalations of marble, calc-schists, black schists, muscovite-albite schists, biotite schists, meta-andesites, metadiorites and porphyritic microdiorites; andalusite-bearing rocks were noted in the float. The flat amphibolites and skarn rocks form the summit levels overlying the steeply-dipping ortho- and paragneisses of the Salado division in the Río Mulatos. Climbing the Río El Placer the change from steep to flat tectonic dips is transitional and probably represents the regional duplex roof thrust at the base of the Cuyuja flat belt.
- (h) **The high level skarnfields continue south of El Placer** as indicated by float in the Ríos Tigre, Niágara Chico and Paracayacu (Niágara Grande). There is a thin steeply-dipping skarn outcrop in this latter river (Dr. A. Egüez, personal communication) interpreted to mark the Llanganates fault; skarn float occurs in its tributary, Río Aguas Blancas (Ing. Diego. Benalcázar, personal communication), whilst at the headwaters of another tributary, Río Pavamicuna, there is a ?klippe of marble overlying the vertical gneisses (Merlyn and Cruz, 1986).
- (i) **No skarns were noted on the El Triunfo-Cerro Hermoso traverse**, but, further south, epidote-magnetite skarn rocks cap the interfluvium west of the Río Verde close to the Baños-Puyo road. This occurrence, which was discovered by Ing. E. Salazar, is the most southerly of the northern skarnfields of the Cordillera Real, at the time of writing.

A regional overview of the northern skarnfields shows them as isolated high-level tectonic klippen along a belt east of the Llanganates fault and west of the sub-Andean fault, lying within the Cuyuja nappe sequence at Urcucocha or thrust directly over steeply-dipping Salado division rocks at El Placer. Andean erosion has everywhere removed the unit except for summit levels which accounts for the previous lack of recognition along valley trails which cross the Andes. In the north the outcrop pattern appears to be controlled by the Urcucocha synform and further skarnfields can be postulated, on a structural and topographic basis, between the Oyacachi and Papallacta rivers, and between the Oyacachi and Sara Urco rivers, where float blocks also indicate its existence.

The northern Cordillera Real skarnfields are of calcic magnetite type (Einaudi et al., 1981), which, on a worldwide basis, are usually related to diorite intrusions within island arc sequences (andesites, sediments and thin limestones). For the northern skarnfields the Upano subdivision (2.7.2) of andesites, sediments and marbles is an excellent candidate for the protolith, with the andesites yielding the epidote skarns, as seen in the field, and the sediments, the garnet skarns. Similarly, the Azafrán subdivision of granodiorite-diorite would correspond to the plutonic phase to provide the contact metamorphism/metasomatism. However, the northern skarnfields represent the eroded relics of a skarn thrust sheet at least 150 km long.

This can be explained if the intrusive phase occurred during the movement of the Llanganates thrust fault which eventually developed into the Cuyuja nappes. Thus, the Azafrán complex would have had been hot at depth along the Llanganates fault but cold at higher levels where it is tectonically overlain by the skarnfield klippen; the Llanganates thrust fault continuously moved skarnified Upano subdivision rocks up and away from the hot pluton to produce a continuous tectonic slab of skarn rocks. Support for this model is also found geographically in the association of skarnfields and skarn float with the Azafrán plutonic phase, and independent evidence, e.g. at Cerro Hermoso, of a syntectonic intrusive phase. Thus, the skarnfields are thought to be derived as a single sheet by movement of Upano subdivision rocks in contact with the Azafrán pluton along the Llanganates fault. Thus, as the petrographic and field data indicate, the skarns overprinted an early phase of regional tectonics and were latter affected by the major high-level nappe tectonics.

2.10.2 The Nambija skarns

No detailed field studies have been undertaken by the project over the Nambija area where the gold mines of Nambija, Cambana, Campanilla and Guaysimi are hosted in skarn rocks. However field and analytical information by Clarke and Viteri (3) and petrographic data from Beddoe-Stevens (2) and Fortey (4), combined with mining company data and a regional assessment (Salazar, 1988) indicate an entirely different geological environment to that of the northern Cordillera Real skarnfields.

Lithologies comprise the plutonic Zamora batholith cut by subvolcanic centres and associated with andesitic and dacitic lavas and tuffs, with minor marbles and calcareous volcanoclastics: possibly an arc-fringing reef environment. The carbonate rocks may belong to the Late Triassic Isimanchi subdivision. However, the subvolcanic microdiorite, centres which, along with N-trending faults, appear to control the small, scattered skarn deposits may or may not be Zamora batholith (Jurassic)-related. Indeed, there are Tertiary volcanic centres which cut the Cretaceous Hollín Formation further east (E. Salazar, personal communication). However, whatever the age, the skarns are found in a “cratonic” area without evidence for regional, penetrative, tectonometamorphic events. Thus, they are autochthonous and contrast with the allochthonous skarn klippen of the northern Cordillera Real.

The skarn protoliths at Nambija are derived from the volcano-sedimentary sequence; one sample (3) showing a crystal-rich andesitic tuff made over to grossular skarn. A feature of these skarns is the presence of non-isotropic garnets with distinctive growth patterns. The skarns have undergone later alteration which fluid inclusion studies (2) indicate at epithermal temperatures with increased salinity; the gold was deposited during this process (see also 3.2.1).

2.11 Cretaceous geology

2.11.1 Cretaceous sediments and volcanics

In the Oriente, the rocks of the pre-Cretaceous basement are unconformably overlain by the 80-240 m-thick, white, quartzitic sandstones of the Hollín Formation of Aptian-Albian age, 105-115 Ma (Bristow and Hoffstetter, 1977) and derived from the east. This is conformably overlain by the 200-800 m thick Napo Formation composed of marine black shales and limestones of middle Albian (105 Ma) to Lower Campanian (80 Ma) age; in turn overlain by the 300-1000 m-thick red-beds of the Tena Formation, derived from the west, of Maastrichtian (75 Ma) to possibly Lower Palaeocene (65 Ma) age (Baldock, 1982). The road section from El Chaco to Río Salado exhibits a 100-200 m transition zone between the Hollín and Napo Formations with volcanic beds.

Along the sub-Andean region, in the narrow belt between the sub-Andean and Cosanga-Méndez faults, these Cretaceous formations are involved in a Late-Tertiary imbricate thrust belt, which affects Miocene units (Baldock, 1982).

In the west of the Cordillera Real, outcrops of the Maastrichtian Yunguilla Formation appear to unconformably overly the Guamote and Alao metamorphic subdivisions north of Cuenca. They comprise black shales, tuffs and tuffaceous sandstones. Intercalated andesitic lavas were noted along the Río San Pedro and some of the greenstones along the road from Azogues to Pindilig appear to be intercalated with basal Yunguilla tuffs, though Bristow et al. (1975) place them in the metamorphic sequence on the Cañar geological sheet. These andesites are similar to those referred to as Piñón Formation on the same sheet which also crop out east of Guasuntos where they are thrust at low angles over the black slates of the Guasuntos metamorphic subdivision (2.2.1). Further north, south of Pungalá, there are basaltic greenstones ascribed to the Cretaceous on Map 2A, but which may be related to the Pungalá pluton of 42 Ma.

2.11.2 Cretaceous granitoids

Nine K-Ar dates for the Pimampiro pluton (3) give a range of 47 Ma to 94 Ma. However, concordant hornblende and biotite ages gives 81 ± 3 Ma. The pluton is a granodioritic body with megacrystic hornblende, located in the extreme north of the cordillera.

Five K-Ar ages on the Magtayán granodiorite (3) indicate that this intrusion was emplaced around 75-80 Ma. This body crops out east of Alausí. Kennerley (1980) reports similar K-Ar ages.

Both these granitoids are undeformed stocks along the west of the Cordillera Real and others of similar age may be buried elsewhere by the Cenozoic volcanic cover.

2.11.3 The Tampanchi mafic-ultramafic complex and possible correlatives

A mafic-ultramafic plutonic body was discovered at Tampanchi (2) along the road east of Taday where Bristow et al. (1975) reported amphibolites. Further geological studies were undertaken (3; Pozo, 1990); K-Ar studies gave three dates between 60 Ma and 66 Ma (4), essentially spanning the Cretaceous-Tertiary boundary.

The Tampanchi Complex has a rough oval plan about 8 km by 4 km. The central core zone comprises ultramafic serpentinites and olivine-clinopyroxenites. This is bounded by a zone of pyroxenites (hornblende augitites) with cumulus textures; followed outwards by hornblendites and hornblende gabbros, pegmatitic in places; and finally, fine-grained hornblende basalts which may be hornfelsic in places. More detailed petrographic descriptions are found in Fortey (4).

The Tampanchi suite represents a hornblende calc-alkaline plutonic complex dominated by a trend from massive fresh cumulus augitite towards increasing proportion, of hornblende and, at a later stage, to the increasing importance of plagioclase.

Local shearing occurs in the Tampanchi complex but the main lithologies are both undeformed and unmetamorphosed; small granitoid and dioritic phases may be present, but it is not clear how they relate to the main complex. The presence of pegmatitic gabbros, the lack of orthopyroxene and the apparent concentric pattern of the complex point to an Alaskan pipe origin (Taylor, 1967); such rocks have now been identified in the Urals and Venezuela (Murray, 1972), and Australia (Anon, 1988).

Kennerley (1980) reported a K-Ar date of 85 ± 3 Ma from a “hornblendite” further north at Magtayán, and project Annual Reports (2, 3) have suggested a correlation with Tampanchi. Ing. D. Benalcázar (personal communication), following up these suggestions, discovered a hornblendite complex south of Laguna Magtayán and a small outcrop further west by the road. Like the adjacent granodiorite (2.11.2), these outcrops are inliers within the Cenozoic volcanics and do not indicate the full extent of the plutons.

Hornblendites and hornblende gabbros of Tampanchi-type are also found in outcrop close to the village of El Azul, between Tampanchi and Paute and also upstream from Shumir, south of Paute (Ing. L. Quevedo, personal communication). Float blocks indicate the presence of another complex south of the Río Upano. All these occurrences are shown tentatively on Map 2B which thus indicates five Tampanchi-type complexes forming a chain of possible Alaskan-type occurrences all cutting the metamorphic rocks of the Alao division.

2.11.4 Late Cretaceous-Early Tertiary K-Ar age resetting

Many pre-Cretaceous units of the Cordillera Real basement give reset K-Ar ages in the region of 55-85 Ma. This is true for the Sabanilla gneisses (2.6.5), the Tres Lagunas granites (2.6.1) and the Cordillera Real schists dated by Herbert and Pichler (1983), Kennerley (1980) and Feininger and Silberman (1982); such dates led Feininger (1982) to propose that such schists were Cretaceous in age.

Over certain small sectors the K-Ar clock is not reset and this is particularly notable over the Zamora division east of the Cosanga-Méndez fault: i.e. over the cratonic zone. Thus K-Ar ages over the Zamora batholith (2.8.1) are interpreted to be a better indication of plutonic ages than the Rb-Sr dates.

It seems clear that the rocks west of the cratonic front were reactivated at this time with corresponding argon release. Possible events related on this reactivation include the subduction system which produced the Magtayán-Tampanchi plutonic chain and the Cretaceous volcanics; and the collision of the western Cordillera (2.13.2). In the field it is difficult to define a tectonic imprint of this age but it is possible that the folding and shearing which affects the Yunguilla Formation and Tampanchi Complex, and the SE-directed overthrusting of the Cretaceous volcanics over the basement east of Guasuntos may be manifestations of this event. The latter thrusting is related to the 70°-trending open-to-tight folds in the flat foliation belt of the Guamote metamorphic division. These folds affect small felsic sheets and bodies which are thus probably of Cretaceous age and are found in other western sectors of the Cordillera, e.g. along the Monte Olivo road.

2.12 Cenozoic geology

2.12.1 Cenozoic sediments and volcanics

To the east and west of the Cordillera Real the Cretaceous and older rocks are overlain by Cenozoic sediments and volcanics. Over the Sierra there are numerous fresh-water, continental, sedimentary basins of Miocene-Pliocene age: Chota, Sibambe, Cuenca, Nabón, Loja, Malacatos and Zumba, some of which are precursors of the Inter Andean graben. Great blankets of Quaternary volcanics cover these and older units.

2.12.2 Cenozoic plutons

There are many late, undeformed, granodiorite-diorite plutons cutting the metamorphic rocks of the Cordillera, and the following have now been K-Ar dated as Cenozoic in age:

- (a) **ca. 20 Ma:** Portachuela pluton, near the Peruvian border; based on seven ages (3).
- (b) **39 ± 4 Ma:** small pluton on Gualaceo-Limón road; one age (1).
- (c) **ca. 40 Ma:** Amaluza pluton, Río Paute, based on five ages (Kennerley, 1980).
- (d) **43 ± 2 Ma:** Pungalá pluton; inliers; from four ages (3).
- (e) **58 ± 2 Ma:** pluton on new Catamayo-Loja road, two ages (3).
- (f) **ca. 60 Ma:** San Lucas pluton, north of Loja; average of five ages (1) and four in Kennerley (1980).

There are certain major newly-discovered plutons which remain undated, e.g. Alao Valley, Río Azuela, and these could be as old as Cretaceous in age. The pluton west of Macas and the great Condué granite also requires dating.

Small porphyry stocks or volcanic necks shown on Map 2B are allocated a Quaternary age as feeders for the Quaternary volcanic blanket. One of these, south of Baeza, was dated at 0.54 Ma (Herbert and Pichler, 1983).

2.12.3 *The Andean event*

Movements during the late Miocene and Early Pliocene are attributed to the Andean-event and account for the major uplift of the Sierra region and the general distribution of high and low ground in present day Ecuador (Kennerley, 1980).

Over the Cordillera Real the Andean Event is manifested most markedly along the sub-Andean thrust belt formed as a result of the uplift of the Sierra, the block west of the sub-Andean fault, relative to the Oriente. Along this thrust belt, the region between the sub-Andean and Cosanga-Méndez faults, the Cretaceous formations are deformed by a series of imbricated high-angled movements which locally produced penetrative cleavages. These thrusts affect Miocene formations to the east over the area of the Napo uplift and represent a rejuvenation of older pre-Cretaceous structures. Thus, the Cosanga fault in the north marks the westward change from undeformed to deformed rocks during both the pre-Cretaceous and Andean events.

Further evidence of Upper Cenozoic rejuvenation is found along the Peltetec fault which is both the line of the neotectonic Inter-Andean graben fault and a Jurassic ophiolitic ?suture. Similarly, the San Antonio fault is a neotectonic line with a lens of Quaternary volcanics along its course across the Alao Valley. The Baños front can be interpreted as the present line of the Las Aradas fault in the south whilst the location of the Miocene basins and their later deformation relates to rejuvenation of the old basement structures (see Noblet et al., 1988). It is believed that these faults also controlled the emplacement of the Upper Cenozoic, high-level, epithermal gold-polymetallic deposits over the Cordillera.

2.13 Geological history

2.13.1 *Pre-Cretaceous history*

The present studies over the Cordillera Real have, for the first time, established a geological framework sufficient to form the basis for speculation on its geological history. However, this report is not the place to elucidate all the possible implications of such speculations and instead this summary will confine itself to the basic interpretation and the mentioning of certain possibilities.

The Amazonian craton in the east stabilised in the Proterozoic (Litherland et al., 1985) and during the Palaeozoic was the site for the accumulation of platform deposits (Pumbuiza and Macuma Formations). In late-Triassic times a volcanic rift basin was developed (Isimanchi division with Norian fossils) and during Early to Middle Jurassic times this was intruded by a calc-alkaline volcano-plutonic association (Zamora division) whilst to the east the Santiago reef limestones were deposited. The Zamora division is bounded to the west by the parallel Salado division calc-alkaline magmatic chain with its Upano island arc-type sequence, and it is thought that the Upano rocks can be traced through facies changes into the Misahuallí volcanics of the Zamora division.

Further west lies the enigmatic Loja division bounded, along the Baños front, by a Mid-Jurassic oceanic terrain containing the Alao-Paute island arc and Peltetec oceanic suture. The closing of this ocean from the west by the docking of the Chaucha plate (Aspden et al., 1988) and westward overthrusting of the molassic Guamote division sediments probably marks the main Late Jurassic/Early Cretaceous tectonometamorphic event of the Cordillera accompanied by the thrust stacking of units eastwards, east of the Peltetec fault. Perhaps the collision was oblique (transpressional) to explain both the major overthrusts and evidence for dextral movements along major faults. The tectonic slices of Tres Lagunas granite within the Peltetec mélange and the presence of reworked Ordovician acritarchs in the Maguazo sediments are important in any accretion model.

An elegant model has been proposed (3) involving the generation of the “collisional” S-type Tres Lagunas granite during this Late-Jurassic “Peltetec” collision by friction between the South America and Chaucha-Arenillas plates. However, the age of the Tres Lagunas granite appears to be too old and corresponds more to that of the Sabanilla orthogneisses and the project’s 219 ± 22 Ma (MSWD = 0.4). 10-point Nd-Sm plot for the garnet gneisses of the El Oro metamorphic province (4). This excellent date strongly suggests the age of the collision which produced the Raspas ophiolitic suture of blueschist, serpentinite and eclogite (Feininger, 1980), which trends east and forms the northern limit of the Huancabamba deflection (Fig. 3).

Thus, there is a strong suggestion that during late Triassic times the Isimanchi rift was opening; the Tres Lagunas S-type granite was being emplaced in a collision setting into older rocks of the Loja division (Agoyán and Chigüinda subdivisions); and the El Oro plates were colliding along the Raspas suture. It is thus possible that Loja division rocks are represented in El Oro north or south of Raspas. To explain all this, Fig. 3 illustrates a possible terrane map for Ecuador; Fig. 4, its evolutionary model; and Fig. 5 a view of the Peltetec collision. Clearly there are many possible models especially with the known dextral component for allochthonous emplacement from the SW.

The project hopes to cover the El Oro area as part of the 1990-1992 programme and it is hoped that many of the answers relating to the Upper Triassic history will be forthcoming. Clearly the rotation and docking of terranes will be to the forefront of these.

2.13.2 Cretaceous and Cenozoic history

The Peltetec collision resulted in major uplift represented by the non-sequence between the Misahuallí volcanics and the Hollín Formation unconformity at ca. 115 Ma. Further uplift is manifested in the Maastrichtian by the derivation of the contrasting Yunguilla and Tena formations from the metamorphic cordillera. This uplift was related to subduction and the intrusion of the Magtayán-Tampanchi plutons and the approach and accretion of the oceanic rocks of the Costa and Western Cordillera along the Calacalí-Palenque suture (Aspden et al., 1988). During these times readjustments of the metamorphic rocks west of the cratonic front produced the regional K-Ar resetting (Fig. 5).

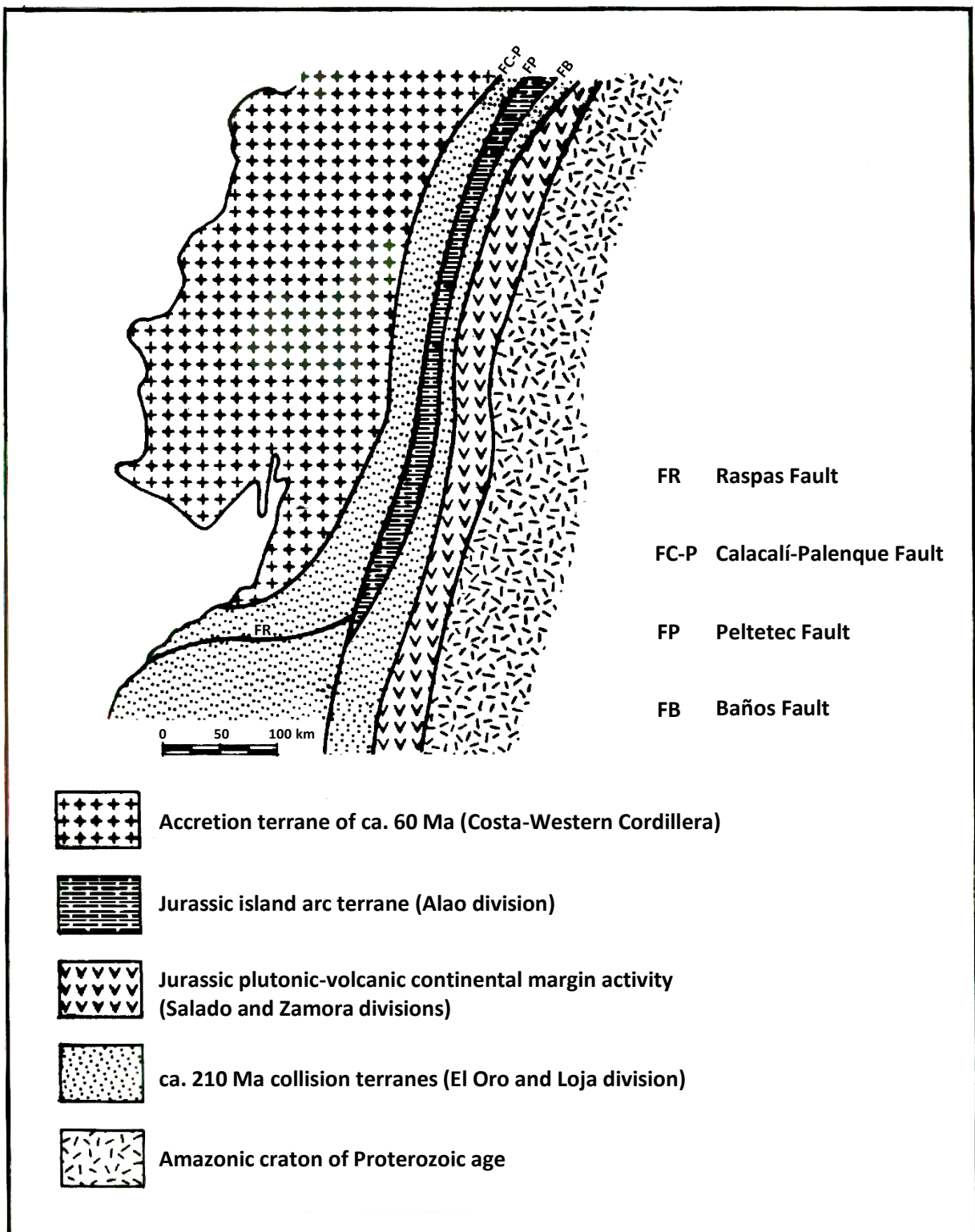


Figure 3. A possible terrane map for Ecuador

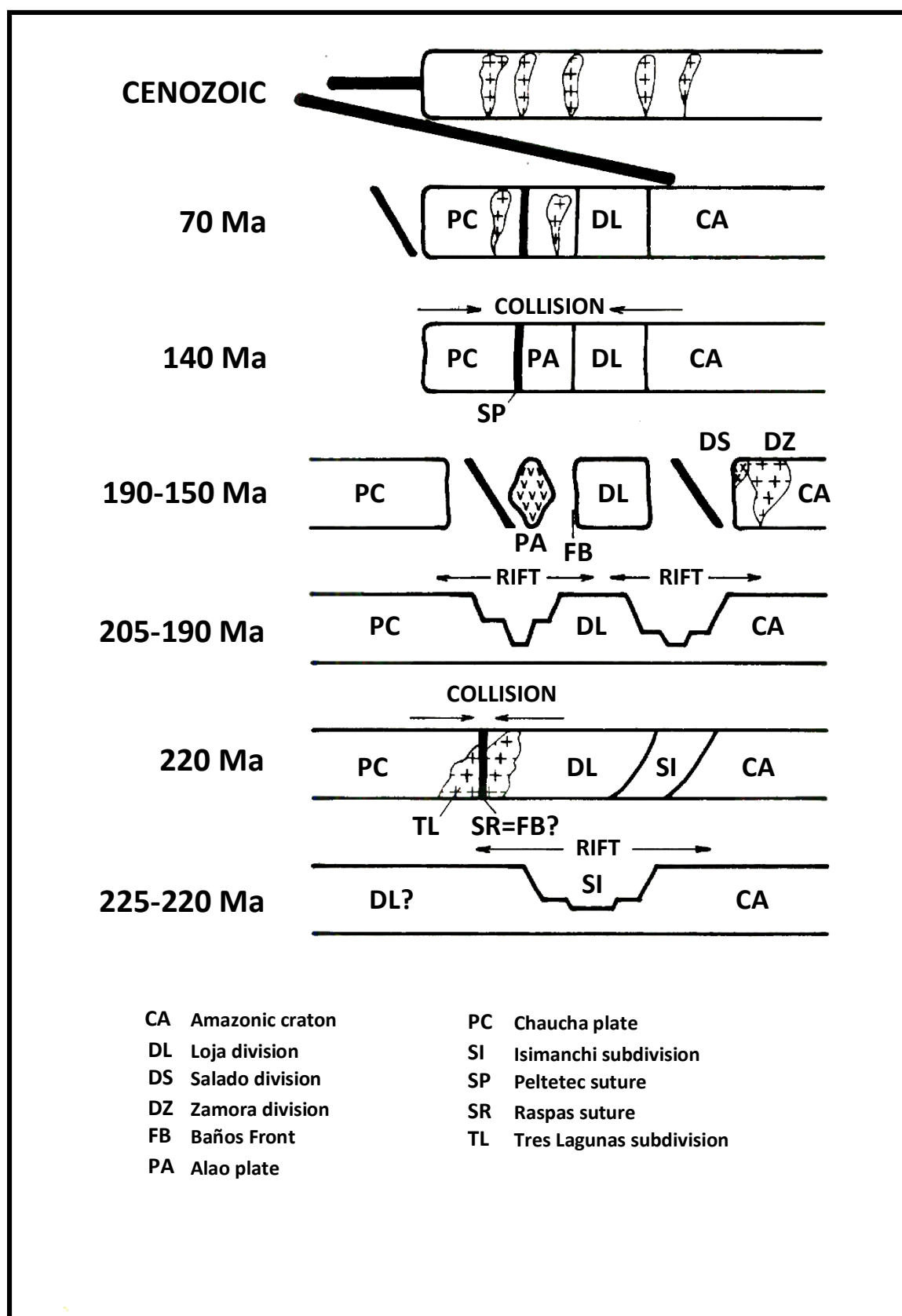


Figure 4. An evolutionary model for Figure 3

The Cenozoic essentially witnessed cycles of “Andean” continental-margin magmatism, related to the subduction of the Nazca/Farallón plate along with Andean uplift and forearc basin evolution over the Costa region of Ecuador (Daly, 1989).

Thus, in terms of the Phanerozoic collision/accretion history; there are three main events:

- (a) **The Late Triassic/Early Jurassic event** determined by project studies over the Isimanchi, Sabanilla and Tres Lagunas subdivision, and in the El Oro metamorphic rocks.
- (b) **The Late Jurassic/Early Cretaceous Peltetec collision**, determined by project studies as the final accretion of the Cordillera Real.
- (c) **The late Cretaceous-Early Tertiary accretion** of the Western Cordillera and Piñón oceanic plate (Costa) (Lebrat et al., 1986).

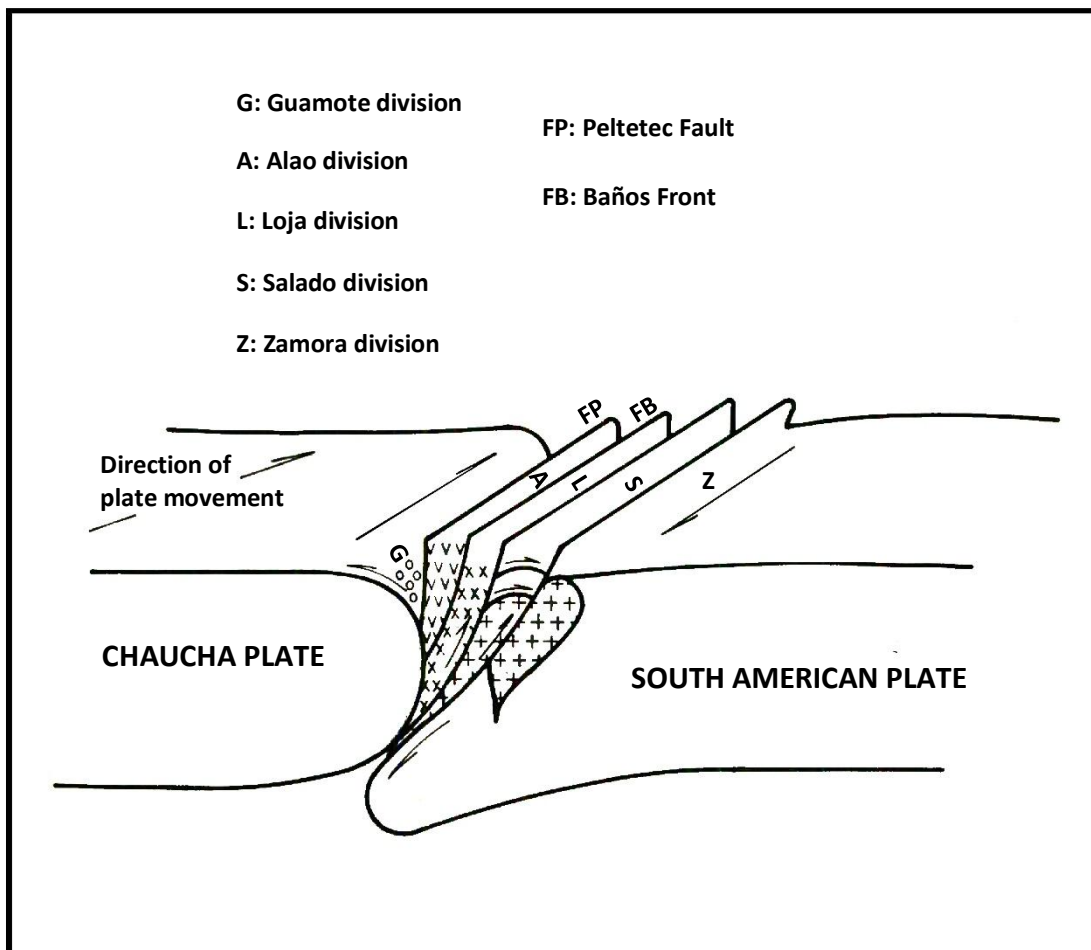


Figure 5. A ca. 140 Ma transpressional collision model

3. MINERAL INVENTORY

3.1 Introduction

As in the Annual Reports, the mineral groupings follow those of the Mining Journal. (1989). Only metallic mineral occurrences and geochemical anomalies are shown on Map 3. The data is mainly from project field traverses, although there are contributions from previous literature and personal geological contacts. At the time of writing Map 3 is short of 75% of the heavy mineral XRF data (which will be included in the 1992 final report), whilst heavy mineral samples for the Catamayo-Loja-Zamora and Saraguro-Loja-Zumba roads have yet to be examined. Map 3 is thus the first stage in a comprehensive metallogenic map of the Cordillera Real and readers must bear this in mind.

3.2 Precious metals

3.2.1 Gold and silver

The mining history of the Cordillera Real has been dominated by these two metals: gold in the 16th century (Navarro, 1986, Vol I), and silver worked later at Condorazo, Pilzhum and San Bartolomé. The presence of gold in most rivers draining the Cordillera is well known (Navarro, 1986; Holloway, 1932) and the study of the associated placer deposits has begun (Pillajo, 1982, Salazar, 1986). Hard rock gold mines and prospects occur in the Zamora district (Map 3B) and there are some geological details on the Nambija mining area (3, Salazar, 1988). This project's contribution lies in the production of a gold map (Map 3); in the correlation of the regional distribution of gold and silver to source rocks; and in the production of metallogenic models which point to new areas of potential.

The gold/silver "inventory" below is a summary of distribution and possible source/metallogenesis from west to east utilising the basement divisions outlined in Chapter 2.

- (a) **There are traces of gold and silver in samples from the Peltetec ophiolitic and Maguazo turbiditic subdivisions (1, 2).** North of Peltetec, in the Valley of Quebrada Quishpe, A. Hirtz (personal communication) reports hardrock gold in ophiolitic rocks associated with the contacts of a later intrusive phase, probably the northern extension of the Alao pluton as indicated on Map 2A. It appears that the low levels of gold in the ophiolite may have been locally reconcentrated at the margins of the granodiorite.

- (b) **Over the Alao-Paute greenstone subdivision and associated El Pan greenschists the main mineral mined in the past has been silver.** This metal was extracted from the Tungurahua and Cubillín mines (Navarro, 1986); thought to be situated in recent volcanics. Further south the Pilzhum and San Bartolomé mines indicate silver:gold ratios in the region of 500:1 (Table 2) and both are polymetallic Ag-Cu-Pb-Zn epithermal prospects related to Cenozoic porphyries (INEMIN-Mis. Belga, 1988). All the Cenozoic prospects probably represent reconcentration/reprecipitation of metals from volcanogenic sulphide deposits in the Alao-Paute greenstones to higher level magmatic hydrothermal deposits related to Cenozoic volcanic activity along rejuvenated fundamental (collision) faults.
- (c) **Within the Alao-Paute belt the Tampanchi mafic-ultramafic complex** may have precious metal potential (see 3.2.2).
- (d) **In terms of present and historic gold mining over the Cordillera Real** the line of the present Baños front/Loja division can be seen to mark the western limits of activity, irrespective of the age of the mineralisation. In the south of the area there is a highland gold belt termed the Collay-Shincata belt (2) which incorporates the present alluvial gold working of the Collay (ca. 50 men), Santa Bárbara-Ayllón (ca. 100 men), Upper Cuyes (less than 50 men), Shincata-Betas (50-100 men) and Upper Yacuambí (ca. 50 men) gold fields (Map 3B) and is ca. 100 km in length. All the gold bearing rivers and streams drain rocks of the Loja division (Tres Lagunas metagranite and Chigüinda semi-pelites) which are cut by Cenozoic granodiorites and porphyry stocks. Scheelite and arsenic occurrences seem to be related to this belt on Map 3B.

Project studies were carried out over the Peggy Mine/Río Ayllón/Río Santa Bárbara sector of this belt (3). In Peggy Mine, values of up to 222 ppm Ag and 0.66 ppm Au were assayed from a prospect related to a Cenozoic porphyry. In the Río Ayllón alluvial gold area old adits are also present. Values of up to 635 ppm Au and 246 ppm Ag were assayed from veinstone samples from one of these; Sb, As, Zn and Pb are also high. Float blocks in the river indicated chalcopyrite schlieren in pelite of Chigüinda-type (with 1.59 ppm Au), and quartz-arsenopyrite veinstone in contact with altered andesitic volcanic rock (with 5.21 ppm Au), indicating mineralisation related to younger Cenozoic volcanics; scheelite was common in the pan concentrates. If this Cenozoic gold source applies to the Santa Bárbara-Ayllón goldfield then it probably applies to the entire Collay-Shincata gold belt.

Gold chemistry (1, 3) of alluvial and primary gold from the Collay-Shincata belt (Table 2) show Ag values in the range 10-30 atom %. These are similar to those of Los Planes and Piuntza and suggest a higher level of formation than Nambija, which accords with the field evidence.

The Collay-Shincata belt of gold and associated metal occurrences appears to stop north of Loja on Map 3B. This is true with respect to alluvial gold workings but the apparent absence of mineralisation may also relate to lack of data: the Saraguro-Loja-Zumba and Loja-Zamora heavy minerals have still to be analysed. In the extreme south, in the Tertiary Portachuela batholith, volcanic phases are related to mineralisation; the samples from the Laguna Cox mineral belt yielded up to 480 ppb Au and 49 ppm Ag.

- (e) **In the north of the area Loja division rocks** yield Ag-Cu-Pb-Zn deposits at Condorazo on the Alao-Palora watershed (Navarro, 1986, Vol II), including the “Royal Vein” rich in silver (A. Hirtz, personal communication). In the extreme north gold was panned in streams draining the Monte Olivo pegmatite belt SE of San Gabriel. These streams drain into the Au-rich Río Minas.
- (f) **The northern skarnfields are gold-bearing in places.** Up to 15 ppm Au was analysed from skarn blocks in the Río Mulatos (1), and this value was confirmed independently; however, chips from the same samples yielded no gold. The El Placer field (2) yielded values up to 46 ppb Au and 5.8 ppm Ag. However, west across the Llanganates, Ing. D. Benalcázar (personal communication) reports gold-bearing skarns from the Río Paracayacu, whilst eastwards Ing. L. Torres (personal communication) reports gold in the Inga skarnfield especially the eastern sector, and this unit is probably the source of the Chalupas-Mulatos alluvial goldfield (Map 3A). Gold was panned close to the Urcucocha skarnfield headwaters of the Río Cosanga where there is an accompanying 12 ppm Ag geochemical anomaly.

Further north there is an Ag geochemical anomaly of 19 ppm in the Río Chalpi de Papallacta. This and the Oyacachi Au-W sector may relate to skarnfields still to be discovered, but could also be derived from younger Cenozoic volcanics like the Au-As-W deposits of the Collay-Shincata belt; an Ag value of 7 ppm was obtained from a fluvial sample from the Río Azuela NE of Cayambe volcano.

The rocks of the northern skarnfields show pale-pink, generally isotropic garnet crystals distinct from the anisotropic garnets associated with the Nambija Au mineralisation. Adularia has been noted (2) but is rare. However, a degree of calcite retrograde alteration is generally present in all the northern skarnfields and skarn blocks studied, which gives rise to the Mo-mineralisation at Urcucocha and Pb-Zn-Cu at El Placer, and a degree of optimism that metalliferous prospects can be found.

- (g) **Traces of gold** are present in the serpentinite bodies east of the Baños front (2, 3).
- (h) **Gold appears related to the Salado-Zamora** divisions in the north of the cordillera. In the extreme north the source of the Río Cofanes goldfield (ca. 50 men working mainly around Puerto Libre) lies partly to the north of La Sofía and may relate to the main mylonite zone; the highest heavy mineral XRF Ag peak so far comes from the Río Cofanes above La Sofía. Another possibility is the ubiquitous garnet-bearing siliceous hornfels rocks, a sample of which gave 2 ppm Ag (4).

Further south, in the Río Oyacachi, Au-As-W indications may relate to the Cu-mineralised epidotised greenstones of the Azafrán plutonic contact zones; a Zn-vein rock in graphitic phyllites from the Río Quijos above the Río Papallacta confluence gave 491 ppb Au and 2.8 ppm Ag (4).

Further south gold is derived from rivers and streams which drain the Abitagua batholith only, e.g. the Anzu and Misahuallí river systems, rather than the skarnfields further west. The origin of this gold is unknown: it may derive from the Jurassic granite/volcanic system or be concentrated by later (Cenozoic) intrusives which cut the granite in places (A. Hirtz, personal communication).

South of the Abitagua batholith, gold is worked in the Río Llushín (20 men) and Río Palora. The latter operation involves about 100 men essentially downstream from and including the Río Coca (4). The source of this gold is unknown but it may be derived from a late (?Cenozoic) volcanic phase which is prominent in the river float.

3.2.1.1 Gold and silver over the Zamora batholith: The main gold area, including all the working hard rock mines and prospects, is in the south of the cordillera and is broadly contained by the limits of the Zamora batholith of Jurassic age.

The recent gold rush has been centred on Nambija, which, along with the Campanilla, Cambana, Guaysimi and Sultana del Condor prospects, is a skarn-related deposit with grades up to 200 gr/t in richest pockets, but averaging 15 gr/t, with a production of ca. 6 t/a. Reserves are estimated in millions of tonnes (Salazar, 1986). Project studies assayed samples up to 442 ppm Au and 17 ppm Ag with very high Au:Ag ratios (Table 2).

The host rocks are pale marbles, sandstones, andesitic-dacitic lavas and tuffs (E. Salazar, 1988). These may be related to a Santiago Formation/Misahuallí volcanic-sedimentary subdivision equivalent of Jurassic age, or to the Upper Triassic Isimanchi subdivision; the Upper Triassic fossils (2.8.5) are reported to have been collected from a partially skarnified Isimanchi ?xenolith near Piuntza.

Summary of the results (1986-1990)

The skarn-producing intrusion phase at Nambija is thought to be the granodiorite/diorite of the Jurassic Zamora batholith; a river block of porphyritic hornblende tonalite from Guaysimi was dated at 151 ± 5 Ma (1). It is thought that the mineralisation occurs along a N-trending fault within a N-aligned xenolith or roof pendant. Pyrite and minor Cu-Pb-Zn enrichment is noted to the east (Rivera, 1988); scheelite and arsenopyrite are also reported (Salazar, 1988).

The skarn rocks are characterised by grandite (grossularite-andradite garnet)-pyroxene (diopside-hedenbergite)-quartz-carbonate assemblages. Grandite may form up to 70 % of the rock and exhibits concentric growth zoning of 1st-order birefringence and sector extinction (4).

EMP analysis (1) shows a variation of $\text{Ad}_{70}\text{Gr}_{29}$ to $\text{Ad}_{45}\text{Gr}_{52}$ in andradite:grossularite proportions, with growth zoning in the direction of higher Ad contents (iron enrichment)

The gold mineralisation is commonly found in calcite-quartz-adularia (low temperature K-feldspar) veins which relate to retrograde carbonate alteration. Fluid inclusion studies (2) indicate that poikilitic quartz in grandite formed at 200°C. This is much lower than the temperature at which the co-existing garnet might be expected to form, indicating that the quartz completely recrystallised during retrograde alteration. Fluid inclusion results for all samples indicate a progression to slightly lower temperatures (150°-220°C) and considerably increased salinity with progressive alteration and mineralisation. Gold analysis (1, 3) for Nambija and Guaysimi (Table 3) indicate low Ag values in marked contrast to the higher Ag of the “epithermal” prospects.

Nambija conforms to classic gold skarn occurrences; though the Au:Ag ratio (20:1) is higher than any on Meinert's (1988) list (max 7:1, Hedley, British Columbia). All, however, occur in clastic or volcanoclastic rich strata, and are associated with mafic diorite to granodiorite plutons of ages from Devonian to Miocene.

The Nambija goldfield is in marked genetic contrast to the other fields of the Zamora batholith: Chinapintza, Piuntza, Vergel-Los Planes, which occur to the east and west of Nambija with apparent north-south alignments within the same plutonic-volcanic complex (Map 3B).

Project studies at Chinapintza (3) assayed samples containing up to 363 ppm Au and up to 250 ppm Ag; up to 5.27 % Zn occurs. The country rock is a coarse-grained granodiorite, extensively propylitised and increasingly cut by quartz veins and porphyry dykes as the mining area is approached. The primary ores are both exo- and endocontact veins and breccias related to a quartz-porphyry body only seen in adits. Some of these have penetrated beyond the oxidised zone and reveal that Pb-Zn-Cu sulphides are prominent filling interstices of a breccia within the porphyry body.

The area of the Piuntza prospect is mainly covered with the remains of a lava and pyroclastic pile of lapilli tuff, pumiceous in places, into which a porphyry body has been emplaced (3). The central breccia is auriferous and gold is also associated with a network of quartz sulphide veinlets in the upper part of the porphyry body. Samples were collected with up to 7.32 ppm Au and 38 ppm Ag; gold analyses show high Ag contents (Table 2).

The Los Planes prospect consists of a wide area of quartz veins and stockworks, hosted by strongly-weathered andesitic-dacitic lavas and pyroclastics (3). The area of interest is part of a much larger area underlain by such lavas and pyroclastics probably forming a volcanic massif consanguineous with the Zamora granodiorite batholith to the west. One sample from a dense quartz stockwork gave 233 ppm Au and 62 ppm Ag; scheelite was noted in pan concentrates: gold analyses show high Ag contents (Table 2).

Table 2. Approximate Gold:Silver ratios for the main mines and prospects from west to east across strike

Zone	Gold	Silver
Pilzhum (Putzer and Schneider, 1958)	1	400
San Bartolomé (UN Revolving Fund, 1979)	1	500
Peggy (3)	1	100
Ayllón workings (3)	3	1
Piuntza (3)	1	10
Los Planes (3)	1	3
Nambija (3)	20	1
Chinapintza (3)	1	10

West of the Los Planes area in the Río Mayo there are narrow copper veins in the Zamora batholith one of which carries 1.12 ppm Au (3).

The mineralisation at Piuntza and Chinapintza is of epithermal type and relates to the emplacement of high-level porphyry stocks of dacitic composition. That at Los Planes is fairly high-level epithermal. All contrast with the skarn-related mineralised at Nambija, which is believed to be directly related to the intrusion of the Jurassic batholith. It is not clear whether the epithermal occurrences are related to the same event or to younger volcanic activity. Apparently Cenozoic volcanic stocks cut the Cretaceous Hollín Formation in parts of the area (Ing. E. Salazar, personal communication): further north the volcanos of Pan de Azúcar and Sumaco are situated at a similar distance from the active continental margin.

Alluvial gold workings are also common over the Zamora area; 50-100 men were occupied along the Río Mayo and about 50 men in the Río Vergel.

Table 3. Variation in gold composition**ZAMORA**

Sample	Location	ATOM % Ag
		10 20 30 40 50
CRMC-64C *	Nambija	—— {11}
JACR-19 *		
JACR-1 *	Guaysimi	—— {10}
#24 #25 #28	Los Planes	{ 5 } ————— {1}
#34 *	Piuntza	{ 7 } ————— {1}
#35		
		{ 4 } —————

COLLAY-SHINCATA

Sample	Location	ATOM % Ag
		10 20 30 40 50
CRMC-25 *	R. Ayllón	—— {10}
CRMC-27A *		
#15 #17 #19	Área del R. Ayllón	{ 1 } ————— { 5 }
JACR-9 #48 #49	R. Collay R. Pílares	{ 1 } ————— {10}
#13	R. Sn. Francisco Mina Peggy	—— {12}
#1 #7 #8 #9A	Área del R. Burro Playa	{ 2 } ————— {12}

* Primary gold

Alluvial gold

() Number of analysis

3.2.2 *Platinum group metals (PGM)*

Navarro (1986, Vol III, Appendix) lists a number of concessions for the years 1900-1920 for gold and platinum from the Pindilig area and Río Cachicorral close by. The discovery by the Project of the Tampanchi mafic-ultramafic complex in 1987 and the recognition of lithological differentiation and cumulate textures prompted speculation that this could be the local Au-Pt sources (2). Since then, a private company has prospected the area and low platinum-palladium anomalies are believed to have been found.

The project has not analysed samples for PGM, but has discovered many ultramafic-mafic occurrences of ophiolitic (see 2.4.1 and 2.9) or Alaskan-pipe type (2.11.3) with which such metals are normally associated.

3.3 Major metals

3.3.1 *Copper, lead and zinc*

There are a number of polymetallic or monometallic prospects/indications involving Cu-Pb-Zn mineralisation. In this review the inventory will be reported from west to east utilising the basement divisions, albeit that many deposits are demonstrably younger and that regional Andean controls on mineralisation may be lateral as well as longitudinal.

- (a) **In the Peltetec and Maguazo** subdivisions there are small Cu occurrences in the serpentinites and Cu-Zn veins in the adjacent Maguazo turbidites (1); a geochemical Zn anomaly is present in the Patate area. At the syncline of Quebrada Totora Yacu (Río Paute) a band of Cu-mineralised cherts and greywackes is found on both limbs at points equidistant from the axial trace, which suggests mineralisation of stratabound-type (2).
- (b) **Over the area underlain by the Alao-Paute and El Pan subdivision greenstones and greenschists** there are many prospects and showings. The Pilzhum silver mine is a polymetallic prospect of epithermal type related to a porphyry stock (INEMIN-Mis. Belga, 1988). It appears to be situated along the southern extension of the San Antonio (basement) fault, which, across the Alao Valley, exhibits later (Cenozoic) felsitic and silicified rocks along its course. Further south, the San Bartolomé mine is geologically and mineralogically similar and is also situated along a fundamental fault (INEMIN-Mis. Belga, 1988). Further north and close to the Baños front structure, are the old colonial silver-polymetallic mines of Altar and Cubillín (Navarro, 1986) sited in Cenozoic volcanics (A. Hirtz, personal communication).

Close to the Baños front, along the Río Paute near the Palaeogene Amaluza pluton, there is a cluster of Zn stream sediment anomalies as high as 2300 ppm (1) which correspond to Zn-Pb-Mo anomalies noted on the Cañar geological sheet (Bristow et al., 1975).

- (c) **Polymetallic Cu-Zn-Pb mineralisation** is also common along the Baños front and within rocks of the Loja division, particularly the Tres Lagunas granite, to the east. In the north there are Pb-Zn traces near Pimampiro (1); Zn indications at Oyacachi; Zn-Cu veins near Agoyán tunnel; and small concordant Pb-Zn-Cu veins in sheared Tres Lagunas granite across the Alao-Palora watershed which probably represent the southern extension of the old Condorazo mining area (Navarro, 1986, Vol II); a sample from this belt gave 3170 ppm Pb (4).

Further south there is an old Pb-Cu prospect near Guarumales before passing into a fairly well-defined belt of polymetallics from Sevilla de Oro through Peggy-Ayllón to Tutupali. Project studies (3) on Peggy Mine samples give a maximum of 6.38% Cu, 1.06% Pb and 31.1% Zn; and from the Ayllón prospect 0.12% Cu, 1.72% Pb and 3.07% Zn. It is thought that the bulk of the mineralisation relates to Cenozoic intrusives which proliferate over this area.

Further south there are Pb and Zn geochemical anomalies related to the Palaeogene San Lucas Pluton. In the extreme south close to Laguna Cox (3), values of up to 2873 ppm Cu, 1086 ppm Pb and 915 ppm Zn were recorded from a sulphide-rich shear zone associated with late porphyries cutting the Neogene Portachuela batholith.

- (d) **Cu-Pb-Zn** mineralisation is widespread in the northern skarnfields. At El Placer values of up to 1347 ppm Cu (from a tourmalinite), 278 ppm Pb and 4279 ppm Zn were recorded (2). Zn up to 578 ppm, is elevated in the Urcuchocha field (3), whilst at the Sara Urco field there are Zn values up to 591 ppm (3).

- (e) **Cu, and to a lesser extent, Pb-Zn**, traces are common in the Salado division especially in mylonitic rocks (e.g. Río Cofanes), and strongly epidotised greenstones (e.g. Río Santa María-Oyacachi) and veins in the intrusive phase. In the metasediments of the Upano subdivision along the Río Upano, weak Cu-mineralisation is found in four greywacke localities which may be a tectonically-repeated stratabound deposit (1).

In the extreme north 4% Zn was recorded from a mineralised sample in Quebrada La Industria (4). The rock is a fine-grained banded “cherty” garnet hornfels of volcano-sedimentary affinity; this marker horizon can be traced west of Rosa Florida but there are also mineralised float blocks further west in the tributaries of the Río Cofanes. Although grouped with the Zamora division, this unit is a transitional with the Salado division.

In the Río Quijos, above the Papallacta confluence, there are blocks of quartz-calcite vein material in graphite schists with value up to 7593 ppm Zn (4).

7189 ppm Cu was recorded from mineralised felsic volcanics cutting the Salado division at Río Tintas near Principal (3).

Cerro Hermoso, the site of legendary wealth, contains only a few small Cu-Zn veins in the carbonate sequence (2).

- (f) **In the Zamora division** of the south of the area, Cu-Pb-Zn occurrence are found associated with the igneous, volcanic and sedimentary subdivisions. Only limited project studies have been undertaken over the Zamora batholith and present mining company gold prospection will have located many more occurrences over this sector.

In the Río Cuyes and Río Yacuambí sectors, strong Cu-Pb-Zn-Co geochemical fluvial anomalies and a Zn mineral showing (4) relate to Zamora batholith/Misahuallí volcanic bedrock. Shearing as young as the Andean event is also present locally and a Cenozoic age for these mineral indications cannot be ruled out.

Further south there are more Cu-Zn-Pb indication related to the three Zamora subdivisions; small galena mineralisation was noted in marbles, close to volcanics, of the Isimanchi subdivision near Valladolid (2).

Cu-Pb-Zn mineralisation was noted at Chinapintza prospect (3), and 5.27% Zn was recorded from one sample.

3.3.2 Tin

Cassiterite and stannite have been reported from Peggy Mine (de Coster, 1986) and project studies have confirmed this; one sample from the mine gave 7684 ppm Sn (3).

Project studies also confirmed the UNDP (1972) cassiterite-scheelite anomaly in panned concentrates in the Río Pichanal, east of Saraguro. This site had float gneissic granite boulders unlike other barren sites nearby which only exhibited young tuff and microgranodiorite.

The remaining heavy mineral cassiterite locations on Map 3 represent merely a few grains.

A sample of muscovite-tourmaline “greisen”/pegmatite collected at the western headwaters of the Río Cuyes from the Tres Lagunas subdivision gave 63 ppm Sn (3), whilst a tourmaline pegmatite from the Monte Olivo pegmatite belt in the extreme north gave 33 ppm Sn (4). This latter is regarded as an extension of the Tres Lagunas granite.

Whilst this Sn mineralisation and that at Saraguro appear to relate directly to the granite or late-stage granite processes, that at Peggy is regarded as related to high level porphyries of Cenozoic age. However, the Peggy mineralisation is sited in the same Tres Lagunas granite and thus the Sn may have merely been reconcentrated/redeposited during Cenozoic times along the Baños front structure.

The highest heavy mineral XRF Sn peak so far comes from a tributary of the Río Yacuambí south of the Río Ortega, near Tutupali.

Apart from the sectors in the Tres Lagunas granite, “greisens” and pegmatites have also been discovered at the headwaters of the Río Sardinas Chico between the Ríos Oyacachi and Quijos (Van Thournout and Piedra, 1986).

3.4 Steel industry metals

3.4.1 Cobalt

A value of 236 ppm Co was detected from a skarn block in the Río Quijos above the Papallacta confluence (3).

A few “moderate” XRF Co peaks have been plotted on Map 3; a cluster occurs around Tutupali.

Two Co geochemical stream sediment anomalies occur in two tributaries of the Río Cuyes, west of Gualaquiza. They form a cluster with Cu-Zn geochemical anomalies.

3.4.2 Chromium

- (a) **Chromium in the Peltetec ophiolite:** unmineralised ultramafic rocks from the Peltetec subdivision show up to 1092 ppm Cr (3), which is standard for worldwide ophiolites (Hutchison, 1983). A. Hirtz (personal communication) reports the discovery of chromite blocks in the hills near the Río Zula in the south of the Peltetec belt. A small Pb-Zn vein close to Peltetec gave 1600 Cr (1).

There is a geochemical anomaly of 651 ppm Cr in the stream draining the serpentinites at Peltetec; further north there are Cr anomalies in the Patate/Pastaza sector probably related to ophiolitic slices.

- (b) **Chromium east of the Baños front:** chromite was identified petrographically in the Soledad serpentinite (4). Further east an unmineralised block from the Urcuchocha serpentinite gave 4079 ppm Cr (3). A serpentinite block in the Río Cofanes gave 2216 ppm; samples from other serpentinite localities give 500-1600 ppm (3, 4).

Chromite grains are noted from heavy mineral samples on Map 3.

The green chrome-mica, fuchsite, is common in the northern Cordillera Real. A sample from an outcrop of fuchsitic serpentinite west of Monte Olivo gave 1410 ppm Cr. Fuchsite may occur in metasediments; a fuchsitic impure dolomite forms a marker band in the Cuyuja nappe pile in the Río Cosanga.

There are Cr geochemical anomalies of up to 422 ppm apparently related to the San Lucas pluton south of Saraguro.

A “strong” Cr XRF peak was detected in a heavy mineral sample from Río Panguri in the La Canela sector, close to vanadium geochemical anomalies.

“Strong” and “moderate” XRF Cr peaks were detected in heavy mineral samples from the Tampanchi mafic-ultramafic complex. These rocks show good evidence for cumulate settling and probably represent the best target area for chromite ore bodies.

3.4.3 Iron

Magnetite is common in the northern skarnfields. These are essentially of calcic-magnetite-type which on a worldwide basis are known for their magnetite ore bodies. So far, however, no large float blocks of magnetite-rock have been observed.

Small float blocks, up to 20 cm across, of magnetite rock were noted along the Río Yacuambí, especially near the confluence with the Río Cambana. They appear to be associated with pyritic hornfels rocks.

There are reports of magnetite-rock float blocks in rivers draining the Zamora batholith (Ing. L. Torres, personal communication).

3.4.4 Manganese

No interesting Mn mineralisation has been noted. A. Hirtz (personal communication) reports vein manganese in the Peltetec region, presumably related to the remobilisation of Mn-rich oceanic sediments. Quaternary wash deposits are reported from near El Carmelo close to the Colombian border in the north, but these are not shown on Map 3.

3.4.5 Molybdenum

- (a) **Molybdenite in the northern skarnfields:** the most interesting Mo occurrence was found along with the discovery of the Urcucocha skarnfield. From the summit of the skarnfield ridge (3), east to Laguan Urcucocha, the exposure wall comprises mainly massive green epidote skarn with a subhorizontal fracture foliation. Fine disseminated molybdenite, together with larger (up to 1 cm) pyrite crystals, are present in the outcrop over a lateral distance of at least two metres but probably less than 10 m. Analyses show 0.3-0.5% Mo (3). Petrologically (4), the platy molybdenite grains are associated with hairline veinlets of carbonate: retrograde alteration of the skarn.

A sample from the Sara Urco skarnfield gave 556 ppm Mo (4), whilst the highest value from the El Placer field was 113 ppm (2).

- (b) **Other molybdenite occurrences:** in the extreme north of the area molybdenite flakes were noted in quartz veins cutting the mafic (pegmatite gabbro) contact zone of the Chingual batholith along the old road to La Bonita. Small Mo-Cu mineralisation was noted in a quartz float block in the Río San Miguel near Monte Olivo (INEMIN-Mis. Belga, 1988). Ribadeneira (1960) reports molybdenite in pegmatites near Hacienda Ilade, Río Anzu.

- (c) **Heavy mineral XRF studies:** there is a cluster of three “weak” Mo peaks from samples from streams draining north into the Río Isimanchi near the Peruvian border. These probably relate to mineralisation in high level felsitic phases within the Portachuela batholith. Another Mo peak occurs in the Río Salado Chico draining an Azafrán plutonic phase west of Macas.
- (d) **Stream geochemistry:** a cluster of Mo anomalies are noted on the Cañar geological sheet (Bristow et al., 1975) coincident with Zn-Pb anomalies, east and west of the Río Paute, near the Tampanchi complex.

3.4.6 Niobium

“Weak” and “moderate” Nb XRF peaks correspond to the Mo-cluster in the Portachuela batholith near the Peruvian border.

3.4.7 Nickel

As with chromium (3.4.2), the nickel occurrences relate to the ultramafic-mafic units.

The highest Ni values of 2061 ppm comes from the Zumba serpentinite (3), whilst the Ni range of 500-2000 ppm from ultramafic rocks of the cordillera are akin to worldwide ophiolite levels (Hutchison, 1983).

There is a geochemical Ni anomaly of 801 ppm (coincident with a Cr anomaly of 651 ppm) from the stream draining the serpentinites at Peltetec.

One sample of the Mulatos skarn contains 5% pyrrhotite (2).

Sauer (1965) reported 1.5% Ni from the Río Mulatos (?Río Paracayacu) ophiolite. These rocks have yet to be rediscovered.

There are no prospects for nickeliferous laterites over the ultramafic rocks of the area; the rate of Andean uplift and erosion is too rapid for the stabilisation of such orebodies.

3.4.8 Tungsten

Rock samples from Peggy Mine gave values up to 5979 ppm W (3); wolframite was identified comprising 60-70% ferberite.

No other rocks with high W content have been noted: 32 ppm W was recorded from a pegmatite cutting Tres Lagunas granite near Loma del Inca (3), and 23 ppm W was recorded from an impure siliceous marble from the El Placer skarnfield (2).

However, scheelite has been noted in panned concentrates throughout the cordillera. The following “scheelite” sectors can be singled out from north to south:

- (a) **Cofanes-La Bonita-Rosa Florida:** a cluster of 20-100 grain scheelite samples.
- (b) **Río Oyacachi-Río Papallacta:** in this district there are six >100-grain scheelite occurrences related to Ag-Au-As-Cu-Pb-Zn showings. No common source can be proposed, but many rivers drain regions where skarnfields are predicted to occur, and where the S-type Tres Lagunas granite crops out. A late post-tectonic source, see (c) below, cannot, however, be ruled out.
- (c) **An important belt trending SW from Peggy Mine-Río Ayllón,** through the headwater region of Río Cuyes to Tutupali, includes five > 100-grain scheelite anomalies related to Ag-Au-As-Sn-Sb-Cu-Pb-Zn showings. This belt essentially straddles the contact between the Tres Lagunas and Chigüinda subdivisions but is also cut by a series of Tertiary and Quaternary intrusives. The two anomalies at the western headwaters of the Río Cuyes are close to pegmatite/“greisen” rocks in the Tres Lagunas granite and also to young volcanic stocks. Clarke and Viteri’s evidence (3) that the Peggy Mine-Ayllón mineralisation relates to late, post-tectonic porphyries would suggest the same source for the entire tungsten belt, possibly concentrated and reprecipitated from the older basement rocks.

3.4.9 Vanadium

Vanadium values of 334 and 289 ppm correspond to the high molybdenum values from the Urcucocha skarnfield (3). A value of 244 ppm was recorded from a garnet granite near Oyacachi (4). Rock samples from the Río Cambana (tributary of the Río Yacuambí) yield 242 and 300 ppm V (4) and it is interesting to note the presence of magnetite in this river (see 3.4.3) and a possible common ultramafic source.

There are vanadium stream sediment anomalies of 296, 316 and 655 ppm in the Río Vergel area in the SE of the area. These correlate with Fe, Ti, Zn and Cu stream sediment anomalies (3) and may also relate to a common ultramafic source.

3.5 Speciality metals

3.5.1 Antimony

Up to 0.49% Sb was analysed from samples from an old polymetallic (Cu-Pb-Zn-As-Ag-Au) prospect close to the Río Ayllón (3). Boulangerite ($\text{Pb}_5\text{Sb}_4\text{S}_{11}$) and bournonite (PbCuSbS_3) were noted. Goossens (1972) reports Sb mineralisation at Pilzhum Mine; UNDP (1972) report the presence of the Sb minerals boulangerite, polybasite and freieslebenite at San Bartolomé mine.

Samples collected from the Laguna Cox mineralised zone associated with felsite dykes cutting the Portachuela batholith yield up to 402 ppm Sb (3).

Two XRF ‘trace’ Sb peaks correspond to heavy mineral samples collected from the mineralised region at the headwaters of the Río Cuyes.

3.5.2 Bismuth

Bismuth has previously been noted in tetrahedrite at Pilzhum Mine (Putzer and Schneider, 1958) and as native bismuth and bismuthinite at Peggy Mine (de Coster, 1986). Project samples from Peggy yielded up to 0.58% Bi (3).

Rock analyses elsewhere show only Bi traces: 29 ppm at the Portachuela batholith occurrences; 14 ppm in the northern skarnfields; native bismuth and bismuthinite were tentatively identified in heavy mineral samples from the Río Mulatos (2).

3.5.3 Cadmium

Samples from Peggy Mine yielded 0.186% and 0.265% Cd (3), and this appears to be a first occurrence over the cordillera; samples from the Ayllón prospect gave up to 120 ppm Cd; and from Chinapintza prospect, up to 410 ppm.

Two float samples with Zn mineralisation give interesting Cd values. A mineralised hornfels from Quebrada La Industria, near Rosa Florida, gave 494 ppm Cd, whilst a mineralised quartz-calcite-graphite vein from the Río Quijos gave 110 ppm Cd.

3.5.4 Rare Earths

“Strong” XRF peaks for caesium, yttrium (and rubidium) are found in a cluster concordant with the Mo anomalies close to the Peruvian border in the Portachuela batholith. The three samples show strong peaks for Ce-Y, Ce-Y and Ce-Y-Rb respectively; the latter also corresponding to the highest Nb peak.

Another “strong” Ce-Y-Rb XRF anomaly occurs from a sample from the Río Numbala, east of Yangana, whilst a Ce-Y anomaly occurs at the western headwaters of the Río Cuyes. Strong Y-Rb peaks are also found from the Tutupali-Ortega Alto sector.

Thorium (27 ppm) and Lanthanum (33 ppm) are elevated in a garnet granite sample from Oyacachi (4), whilst a sample of mineralised quartz vein from the Río Collay gave 22 ppm Th and 29 ppm La (3). 38 ppm Th was recorded from a mineralised (polymetallic) vein from the Alao-Palora watershed belt, and 30 ppm Th from a Sara Urco skarn rock (4).

3.5.5 Titanium

Large brownish-red rutile crystals measuring up to 4 cm in length are found in isolation in pegmatized gneisses east of Monte Olivo. This occurrence is probably of mineralogical curiosity only.

Elevated Ti values of 0.40 and 0.44% are concordant with the highest Mo-V values in the Urcuchoa skarnfield.

Ti stream sediment anomalies of up to 1.04% correspond to vanadium anomalies in the Río Vergel area.

3.6 Industrial minerals, rocks and curiosities

3.6.1 Hot springs

There is a line of E-draining hot springs east of those shown on the map of de Grys et al. (1970). From north to south these are at Oyacachi, Papallacta, Baños, and El Placer (Río Palora, western headwaters). These springs lie close to the Baños front and relatively close to the volcanic centres of Cayambe, Antisana, Tungurahua and Sangay respectively.

3.6.2 Asbestos

Small blocks of tremolite asbestos and small veins of antigorite asbestos are common associates of the northern serpentinites.

At the base of the main (Peltetec) serpentinite in the Huarguallá valley there is a 5 m-thick belt within which slip-fibre chrysotile asbestos is well-developed. At higher structural levels the asbestos forms a vein stockwork. Along the Alao road, near Peltetec, loose blocks contain small veins of blue asbestos.

3.6.3 Barytes/Barium

A mineralised mylonitic granodiorite from near La Bonita gave 442 ppm Ba.

An “extremely strong” heavy mineral XRF Ba peak (with development of second order peaks) was noted from a sample upstream from Chicaña, with corresponding vanadium geochemical anomaly.

3.6.4 Kaolin

Weathered, kaolinitic, feldspar-rich intrusives are common, but no high-quality kaolinite reserves have been noted. Reserves could be found in the syenite/monzonite rocks south of Rosa Florida. Stoll (1962) and Goossens (1972) reported small-scale kaolin production at Puyo and Azogues.

3.6.5 Carbonate

Along the sub-Andean belt there are abundant outcrops of Napo Formation black limestone.

Small travertine deposits over the cordillera are noted on field commission maps.

Great thickness of marble, blue to off-white in colour, belonging to the Isimanchi subdivision occur on the east bank of the Río Isimanchi; south of Isimanchi; and to the east of Valladolid on the Porvenir road (2).

Accessible marble bands also occur along the Ríos Paute, Zula and Negro, west of Méndez (2). White marble float blocks occur in the Río Diviso (3); the Cerro Hermoso black marbles comprise a 500 m-thick unit (2); impure fuchsitic dolomites occur in the Río Cosanga (3).

Small calcite veins are ubiquitous in the greenstones. In the Huarguallá Valley (1), calcite crystals up to 30×20×20 cm in size can be obtained, but these are not of Iceland Spar quality.

3.6.6 Quartz

Pure Hollín Formation quartzites crop out along the right bank of the Río Chuchumbleza (4) and could have potential for a glass industry.

3.6.7 Feldspar

Feldspar-rich rocks include the quartz monzonites and quartz syenites of the Rosa Florida pluton and various microfeldspathic dykes and sheets, aplogranites and aplites. A well-defined pegmatite belt exists north from Monte Olivo. It is unlikely if any of these would be of economic interest.

3.6.8 Gemstones and mineral curiosities

Apart from the rutile megacrysts in the Monte Olivo pegmatites (3) and the idioblastic garnets there are other mineral curiosities.

Green euhedral zoisite crystals are found in pegmatised schists east of Monte Olivo; they could be mistaken for beryl.

An occurrence of sky-blue lazulite (Fe, Mg-alumino-phosphate) was found by Van Thournout and Piedra (1986) at the headwaters of the Río Sardinas Chico. Blocks, presumably from this source, have been noted in the Río Quijos below Borja.

Grains of topaz have been recognised in the heavy mineral study (4). Two samples come from the headwaters/watershed of the Río Sangurima which is only just north of the greisen/pegmatite zone at the Río Cuyes headwaters. It is therefore likely that this topaz has a true greisen source.

Tourmaline is common in the pegmatites; the black schorlitic variety is generally present. No gemstone-quality crystals were noted.

There are no firm accounts of beryl/emeralds in the sub-Andean/Oriente area despite the fact that the conditions of formation of Colombian emeralds (in contact aureoles of Tertiary intrusives cutting Napo Formation equivalents) are fulfilled in Ecuador.

3.6.9 Graphite

Graphitic or carbonaceous shales, slates, phyllites and schists are common throughout the cordillera. Enriched zones are noted on individual field commission maps (1, 2, 3, 4), but no high-grade deposits were found.

3.6.10 Garnet

Garnet is a common mineral over the cordillera where the local inhabitants sometimes refer to it as “ruby”; no large gem quality garnets have been noted.

Garnet-rock of high purity is common in the Nambija and northern skarnfields where they can form bands up to 20 cm thick.

Euhedral, idioblastic, garnets up to 3 cm in size, are present in float blocks in the Río Collanes which drains into the Río Palora from the north.

3.6.11 Magnesite

Small veins of magnesite are common in the serpentinites within the Peltetec subdivision and those east of the Baños front; but they are not of economic interest.

3.6.12 Mica

Small one- or two-mica pegmatites are found along the cordillera (Map 3), but crystals are a maximum 5 cm across and of no economic interest.

3.6.13 Sillimanite minerals

Both sillimanite and kyanite have been noted in the field but their occurrence is of academic interest only.

3.6.14 Ornamental stone

Many new occurrences with ornamental stone potential have been discovered. These include the blue quartz/smoky feldspar granites of Tres Lagunas; the “black granites” (megacrystic gabbros) of Tampanchi; the pink syenites of Rosa Florida; the green/pink/black northern skarnfield rocks; serpentinites (green and black); pale or black marbles; and many granitoid plutons.

3.6.15 Phosphate rocks

There are occurrences of phosphate rock in the Cretaceous Napo Formation of the Oriente (Wilkinson, 1982; Boujo et al., 1984) and are not documented here.

An apatite-rich metagranite collected east of Papallacta gave 2.25% P_2O_5 (2); but this has no economic significance.

3.6.16 Sulphur

Minor amounts of native sulphur, associated with zones of pyritic alteration, are present within the Tarqui Formation between Atillo and Laguna Atillo.

3.6.17 Talc

Talc schists and talcose serpentinites are commonly associated with serpentinite bodies but no large deposits were noted. Two-metre-thick bands of fine, pure, sericitic “talcose” schists were noted near the Río Cugusha (1).

3.6.18 Gypsum

This mineral is mined locally from the Tertiary rocks of the Malacatus basin. Small occurrences of no economic significance have been noted over the metamorphic rocks.

3.7 Energy minerals

3.7.1 Coal

Coal reserves occur in the Miocene Cuenca, Loja and Malacatus basins (Stoll, 1962), but not in the basement rocks.

3.7.2 Oil

Bituminous black shales, probably derived from the Napo Formation, which when hammered give a smell of petroleum, have been found as river blocks in the Río Chingual, Río Salado and Río Vergel (3, 4). Mudstones from the Tertiary Malacatus basin gave a total hydrocarbon yield of 60-80 Kg/tonne (2).

3.7.3 Uranium

A 30 cm band of uraniferous phosphate was reported by Vera (1980) from the Río Chingual near the Colombian border. A project field scintillometer survey confirmed the radioactive anomaly (320 c.p.s.).

A value of 19 ppm U was recorded from a Cu-mineralised gneissic block in the Río Condué (4), and 13 ppm from a tourmaline pegmatite from the Monte Olivo belt SE of San Gabriel (4).

Most field samples including those from pegmatites, have been examined in the office under a portable gamma ray scintillometer, but no anomalously high counts have been noted.

Various weak radiometric anomalies, mostly below 300 c.p.s., were determined from the metamorphic rocks during the national uranium survey (Carrión and Villalba, 1981; Severne et al., 1978). Some relate to small Cu mineralisation in the Zamora batholith along the Zamora-Cumbaratza road; others were found along the Río Paute between Amaluza and Méndez. Uranium stream sediment anomalies up to 5 ppm were detected in the Río Jamboe, east of Zamora, which drains the Zamora batholith. Uranium anomalies were also found in the freshwater Miocene sediments of the Cuenca, Loja and Malacatus basins.

4. METALLOGENIC BELTS AND MINERAL POTENTIAL

4.1 Introduction

The few man years of effort on the Cordillera Real cannot as yet be regarded as a proper basis for the formulation of metallogenic models; especially since the studies indicate major Mesozoic collision/accretion events. These latter are absent from the Bolivian Andes where Sillitoe (1976) proposed systematic changes in metal associations across the belt reflecting the increasing depth of the underlying subduction zone away from the continental margin. Thus, the eastward sequence of iron-apatite, Cu-Mo, Ag-Pb-Zn and Sn-Sb-Bi-W belts were thought to be related to successively younger magmatic events, Jurassic to Quaternary in age (Frutos, 1982). The metals were regarded as components of the calc-alkaline magmas that gave rise to the granite batholiths and andesite-rhyolite lavas. However, Schneider and Lehmann (1977) indicated that the Bolivian magmatic tin belt is related to the remobilisation of Palaeozoic manto-type placers. These metasedimentary stratabound tin deposits form a belt of more than 600 km and it is remarkable that exactly over this sector the Mesozoic and Cenozoic magma-related tin deposits are successively situated (Frutos, 1982).

For Ecuador the growth of the South America plate ceased in the Early Tertiary. The rocks of the Cordillera Real represent episodes of Triassic-Jurassic growth and their elements have been assigned to five major lithotectonic division in this report. During the Cenozoic, these same rocks in the form of consolidated continental crust have been fractured and intruded by calc-alkaline magmas generated by the (?shallow) subduction of the Farallón/Nazca oceanic plate. It is clear from Chapter 3 that these later magmatic events are important in terms of metallic mineral concentrations.

From the limited data available there are indications, clearer in some cases than in others, that the lithotectonic divisions form their own metallogenic provinces irrespective of mineralisation age or style and that fundamental structures, e.g. the Baños front, mark both province-transitions and channels for the later mineralisation. In the following sections the metallogenesis and mineral potential of each is treated separately.

4.2 The Peltetec and Maguazo subdivisions (Au-PGM-Ni-Cr-Mn)

The ophiolitic igneous fraction of this unit, which only occurs north of Río Cebadas, is mantle-derived and is associated with traces of Cr-Ni and Cu. Cu, Zn and, possibly, Mn mineralisation is found in the Maguazo turbidites and volcanics. Reported gold concentrations from Quebrada Quishpe relate to the margins of a later Cenozoic granodiorite and such sites would constitute the best exploration targets for gold: i.e. Cenozoic mobilisation and concentration.

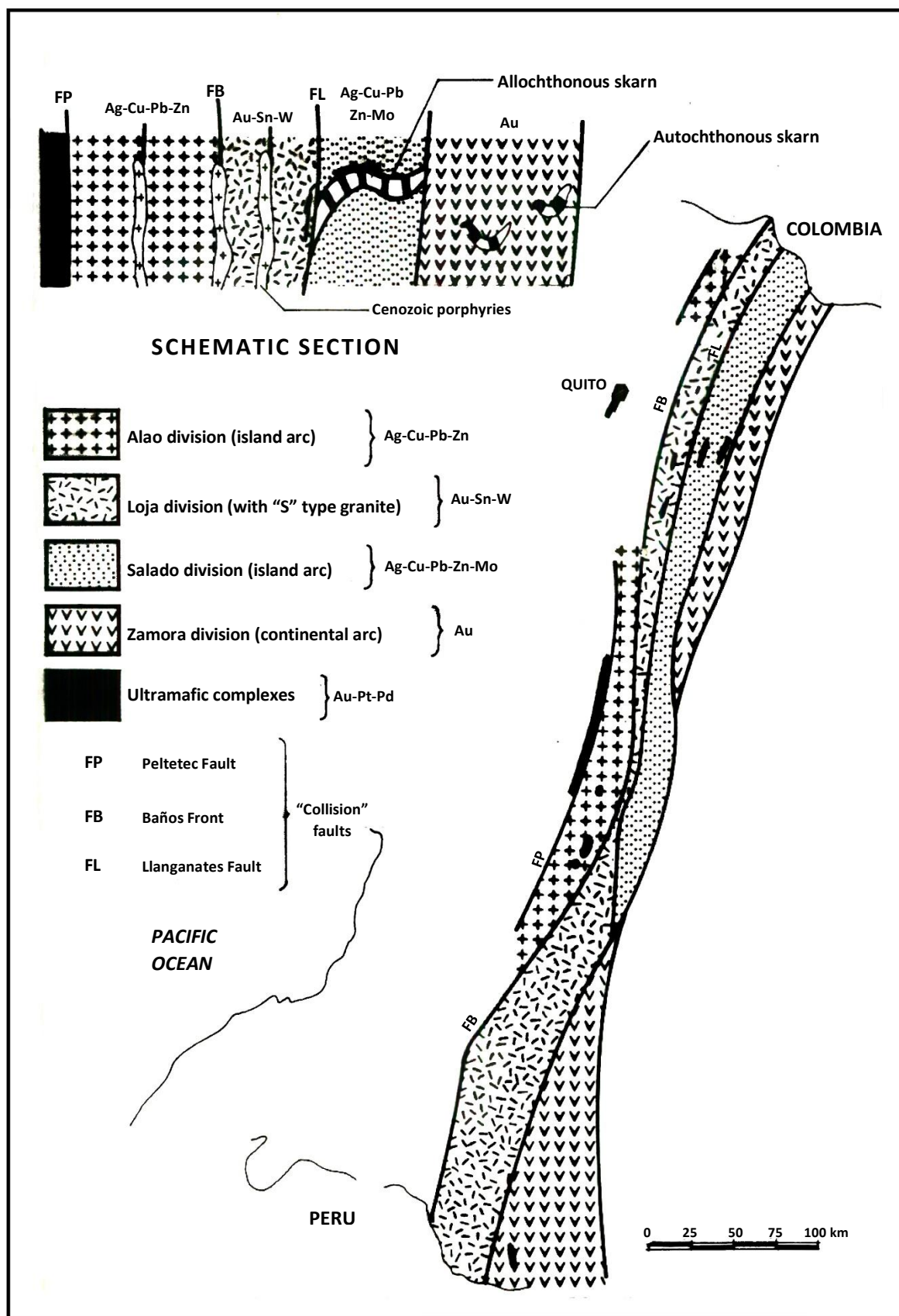


Figure 6. Metallogenic belts along the Cordillera Real

4.3 The Alao-Paute and El Pan subdivisions (Ag-Cu-Zn-Pb)

This is an island arc andesitic greenstone belt with polymetallic Ag-Cu-Pb-Zn potential; gold is not worked. It may be significant that the high geochemical Zn anomalies are found in the El Pan metasedimentary sequence.

The main polymetallic workings of Pilzhum and San Bartolomé are epithermal porphyry-related deposits regarded as Cenozoic in age and sited along Andean-trending faults. At Pilzhum the fault can be attributed to the rejuvenation of the San Antonio ‘collision’ fault which divides the Maguazo and Alao-Paute subdivisions. In the Alao Valley this rejuvenation event is marked by a mappable lens of felsic volcanic and silicification along the same fault; nearer Pilzhum the fault rejuvenation produced the small Miocene Biblián Formation basin (Cañar sheet: Bristow et al., 1975). There is also abundant evidence for the rejuvenation of other collision faults such as the Peltetec fault (see 2.3). Thus, it can be proposed that the Cenozoic fluids were channelled along these faults during their rejuvenation and that these lines should thus be prospection targets especially over relatively inaccessible areas where there is little or no data.

It is thought that the polymetallic Ag-Cu-Zn-Pb deposits related to the Alao-Paute arc were originally volcanogenic sulphides, possible of Kuroko-type, related to the island arc formation and remobilised first during collision and later in the Cenozoic.

4.4 The Tampanchi plutonic chain (Au-Ag-PGM)

This Late Cretaceous mafic-ultramafic chain of “Alaskan pipes” is almost certainly derived from mantle tholeiites with little or no crustal contamination. Thus, it cannot be considered as a “metallogenic belt” with crustal signature. Tampanchi-type plutons must be regarded as exploration targets for precious metals, and any future work in the cordillera should keep an eye out for the diagnostic lithologies: coarse hornblendites, pegmatitic gabbros and pyroxenites, especially over rocks west of the Baños front.

4.5 The Loja division (Au-W-Sn)

From the limited data available the Alao/Loja transition, the Baños front, marks a change from the polymetallic Ag-Cu-Pb-Zn “Alao” mineralisation to Au-W-Sn “Loja” mineralisation.

At the time of writing, tin (Sn) mineralisation in Ecuador is confined to Peggy Mine and the heavy mineral cassiterite anomaly east of Saraguro. The former is related to a Cenozoic porphyry within Tres Lagunas granite close to the Baños front; tourmaline is widespread. The latter is probably derived from the Tres Lagunas granite. Other tourmaline pegmatites related to the Tres Lagunas granite from the Río Cuyes headwaters, and in the extreme north, the Monte Olivo pegmatite belt, give weak Sn concentrations. From this it seems apparent that, as in the case of Bolivia, the young tin deposits of Peggy Mine are remobilised from the crust, in this case the Sn-bearing Tres Lagunas granite: an S-type granite with high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios comparable with the S-type (Hercynian-type) tin-tungsten granites of Malaya (Hutchison, 1982).

Scheelite is common in heavy mineral concentrates along the Collay- Shincata gold belt, although only rock samples from Peggy Mine have yielded high W values. Arsenic (As) also seems to be related to this Au-W belt which may also be present in the Oyacachi area in the north; antimony (Sb) could also be used as a pathfinder for gold (3).

Based on the Peggy-Ayllón observations (3) it is probable that the Au- scheelite showings relate, at least in part, to later (Cenozoic) high-level porphyries, although Au-scheelite mineralisation directly related to the Tres Lagunas granite, e.g. the Japanese deposits (Ishihara, 1982), cannot be ruled out. The Collay-Shincata belt does in fact appear to occur over both the Tres Lagunas granite and the adjacent Chigüinda semipelites of the Loja division.

Thus, the Loja division appears to mark an Au-Sn-W belt with mineralisation concentrated, at least in part, by later porphyries which reconcentrated the metals at higher levels. Prospection areas for gold are now better-defined using Map 3B; whether there are economic deposits of tin and tungsten remain for future exploration of these strategic resources.

4.6 The Salado division and northern skarnfields (Au-Ag-Cu-Pb-Zn-Mo)

The model for the formation of the northern skarnfields (2.10.1) involves the thrusting of a sheet of Upano subdivision island arc volcanics and sediments over the hot Azafrán batholith to form a skarn thrust sheet, eventually uplifted and eroded into individual klippen. For El Placer and Urcucocha the klippen are in the region of 200 m thick and comprised 50% or more skarn rocks intercalated with tectonic slices of other lithologies. Thus, instead of skarn “pockets”, as found at Nambija, related to static contact zones, huge volumes of skarn rocks are present related to the movement of a continuous sheet along the intrusive contact.

Although no high gold values comparable to Nambija have been found so far in the northern skarnfields and skarn blocks, gold showings are reported and it is possible that the Chalupas-Mulatos alluvial gold field is derived from the Inga skarnfield. Au-Cu-Pb-Zn mineralisation is present in outcrops at El Placer and Mo-mineralisation in outcrop at Urcucocha, both associated with retrograde carbonate veinlets. Although the skarns are overall of magnetite type, their unique mode of formation probable exempts them from the classification by metals as proposed by Einaudi et al. (1981).

Assuming the plan of the Urcucocha skarnfield on Map 2A, over one billion tonnes of skarn rock can be predicted. It is such volumes of material yet unexplored, combined with the mineral indications noted by the project and others, which make the northern skarnfields, and those yet to be discovered, prospection targets.

The mineralisation in the northern skarnfields clearly relates to Mesozoic skarn formation and not to Cenozoic remobilisation. Similarly, there are other lithotypes within the Salado division which could be classified as potential prospection targets: the epidotic greenstones at the Río Oyacachi/Río Santamaría confluence area, and the siliceous garnet hornfels rocks found as Zn-Cd-Cu mineralised float blocks and outcrops around La Sofía and Rosa Florida. The pluton west of Macas is also worthy of follow-up studies.

4.7 The Zamora division (Au)

The Nambija goldfield of skarnified marbles and volcanoclastics is regarded as of Jurassic age. The epithermal deposits of the adjacent Chinapintza, Piuntza and Vergel-Los Planes fields are probably of similar age with the possibility of Cretaceous or Cenozoic volcanic redeposition. All the main prospects lie within the Jurassic Zamora batholith and there is an apparent north-south structural control on the gold mineralisation.

Although there appears to be gold mineralisation related to the Jurassic plutonic/volcanic pair at Abitagua, the Zamora batholith can be singled out as a gold-rich, I-type plutonic/volcanic complex containing classic gold skarn occurrences (Meinert, 1988). It may be that the high gold content of the Zamora batholith region relates to a skarn protolith gold component and in this respect, it is interesting to note the presence of the calcareous/volcaniclastic skarn protolith common to all gold skarns (Meinert, 1988) which is absent at both Abitagua and Rosa Florida in the north. This sequence is most likely to be a correlative of the Upper Triassic Isimanchi subdivision since the fossils which indicate this age come from partially skarnified xenoliths in the pluton; though a correlation with a tuffitic Lower Jurassic Santiago Formation equivalent cannot be ruled out.

Thus, there is the possibility of relating the Zamora batholith goldfield not to the mantle-derived batholith but to a pre-existing volcano-sedimentary basin of probable rift origin, of a type increasingly regarded as the primary source of the world's gold deposits (Plant et al., 1989).

5. CONCLUSIONS

The geological studies undertaken during the four years of the project have embraced many specialisations of the science (see 1.13) in order to present a reasoned model for the history of the geology and associated mineralisation. Many new geological units have been discovered and these have been assessed in terms of their worldwide mineral potential. These have included the following:

- (a) The Peltetec ophiolitic belt of Jurassic age.
- (b) The island arc greenstone belts of Alao and Salado of Jurassic age.
- (c) The Tampanchi chain of Cretaceous “Alaskan pipes”
- (d) The “Hercynian” S-type granite chain of Tres Lagunas of probable Triassic age.
- (e) The Andean I-type batholith chains of Azafrán and Zamora of Jurassic age.
- (f) The Cenozoic chain of porphyries.

The bulk of these are pre-Cretaceous in age and related to discrete accretionary events. They form belts of crust with particular metallogenic signatures, despite the remobilisation of the metals by Cenozoic “Andean” I-type porphyries along fundamental faults related to the initial accretion.

In the northern cordillera, a chain of skarn klippen (erosion outliers of nappes or thrust sheets) 150 km long has been discovered. To the present compiler’s knowledge this is a unique geological phenomenon and has no analogues for comparative assessment of mineral potential.

In the remaining two years of the project, further studies will be made on the economic potential of the Cordillera Real. During this phase the geological and metallogenic maps (Maps 2 and 3) and this present report will all be upgraded for eventual publication. Studies will also be carried out on the El Oro metamorphic province and National Maps on the scale of 1:1 million will be prepared. The policy of objectivity in all aspects, including stratigraphic terminology, will be maintained, in order to make a significant contribution to the science in Ecuador.

Finally, it is hoped that this report will help to promote geological activity in the cordillera; both mining and academic. The new geological units and structures outlined in Chapter 2 would, if Ecuador were a European country, result in a PhD battleground. These units and structures have been related to metallogenic belts and thus the database represented by the Annual Reports and the Regional Maps 2 and 3 should be valuable in the initial justification of investment and in the selection of areas for mineral prospection.

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